
MISSISSIPPI ENVIRONMENTAL GEOLOGY
David T. Dockery III and David E. Thompson
Mississippi Department of Environmental Quality
Office of Geology
Second Edition, 2019

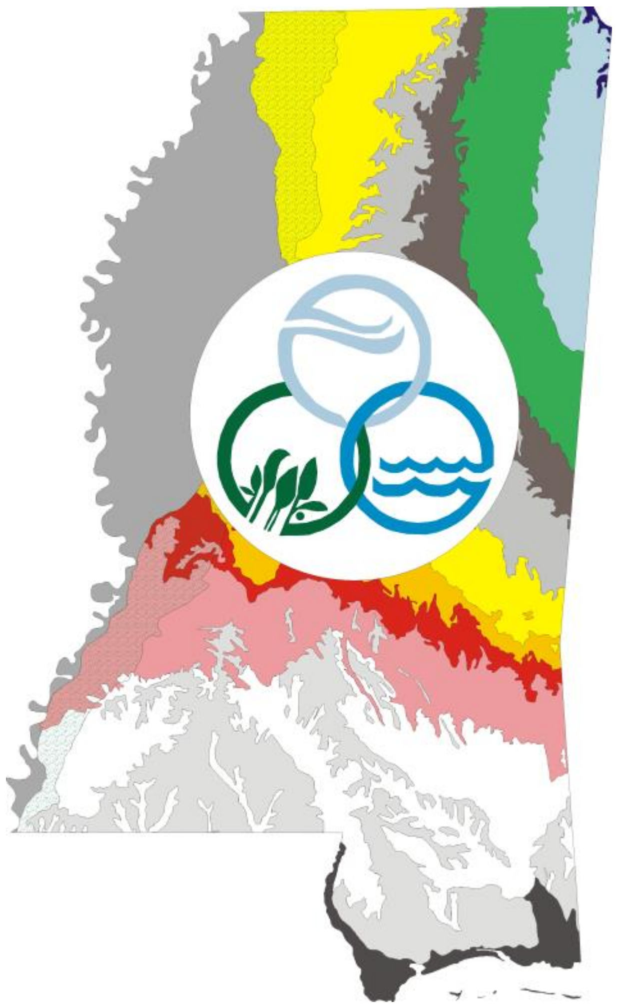
MISSISSIPPI
OFFICE OF
GEOLOGY

MISSISSIPPI DEPARTMENT OF
ENVIRONMENTAL QUALITY

THE GEOLOGICAL SURVEY
OF MISSISSIPPI SINCE 1850

MISSISSIPPI ENVIRONMENTAL GEOLOGY

David T. Dockery III, RPG
David E. Thompson, RPG



Mississippi Department of Environmental Quality
Office of Geology
Second Edition, January 2019

The authors dedicate this book to their wives; we were both very fortunate and blessed to have them for many happy years.


In Memoriam: Janice Lynn Thompson, 1959-2013, with her sons PJ, Luke and Brandon (left to right), her heart and her world.


Mary Elizabeth Yonkers Dockery, March 31, 1949— November 25, 2017, collecting fossils at Le Guépelle, France, next to a Scottish Thistle, July 17, 1983.

Second Edition, January 2019

Contents

Chapter 1. Physiography, Ecoregions, Major River Basins, Surface Geology, Soils and Surficial Geochemistry ……………..… Page 7

Chapter 2. Ground Water …………………………………………….. Page 33

Chapter 3. Floods and Low Water ………..…………………………….. Page 64

Chapter 4. Slope Failure ………………………………………..…. Page 88

Chapter 5. Foundation Failures ………………………………………… Page 120

Chapter 6. Rivers and Pollution ……………………………………... Page 139

Chapter 7. Mines and Mine Reclamation …………………...………. Page 169

Chapter 8. Solid Waste Disposal ……………………………...…….. Page 181

Chapter 9. Energy ……………………………………..………….. Page 190

Chapter 10. Geology and Public Health ……………………….………. Page 202

Chapter 11. Sink Holes and Karst Hazards …………………….……. Page 262

Chapter 12. Dam Safety ……………………………….…………….. Page 271

Chapter 13. Salt Domes ………………………………………………… Page 291

Chapter 14. Coastal Geology …………………………………………… Pager 311

Chapter 15. Emergency Management ………………………………… Page 331

Chapter 16. Climate Change ……………………………………………. Page 358

Chapter 17. Strategic Resources ……………………………………… Page 382

References Cited ………………………………………………….. Page 388

CHAPTER 1. PHYSIOGRAPHY, ECOREGIONS, AND SURFACE GEOLOGY

Mississippi is within the Gulf Coastal Plain Physiographic Province, and its land surface is largely underlain by unconsolidated sediments that range in age from Recent to Late Cretaceous. Reverend Elias Cornelius (1819) gave one of the earliest geologic descriptions of Mississippi in a paper on his travels between Boston and New Orleans. Here he referred to the Gulf Coastal Plain as the "Alluvial Formation," observing its northern limits to be south of the Tennessee River's southern "Dividing Ridge," or as travelers called it, "the southern boundary of the *stony country*." His description in part of the land south of the Tennessee divide follows: "After crossing it, you see no more limestone; and, which excites more joy in the traveler, no more of the silicious gravel, with which it is associated, and which is so troublesome to the feet of horses. The soil consists of a soft clay, or light sand, on which you seldom meet with a stone of any kind. The surface of the earth is undulating and hilly, but not mountainous."

The state's highest elevation is the top of Woodall Mountain (**figures 1-3**) in Tishomingo County, a coastal plain "summit" at 806 feet. The term mountain for this hill is a misnomer as there are no mountains on the coastal plain. Rather, cuestas of high relief and elevation are formed on sandy strata, which absorb rainfall and have less runoff. The term "cuesta" was used by Davis (1899) to describe escarpments typical of coastal plain landscapes. Such landscapes develop on the homoclinal flanks of subsiding basins, such as the Gulf Coastal Plain, and form parallel, outward-facing, belted, erosional escarpments or cuestas (Martin, 1966, p. 2285). Soils developed on shaly or chalky formations erode to form the low-relief prairies, which separate cuestas. Lobeck's (1979) "Physiographic Diagram of the United States" showed three unnamed cuestas trending across the Gulf Coastal Plain of Alabama and Mississippi, which correspond, from north to south, the Wilcox, Tallahatta, and Catahoula/Miocene cuestas.

The most detailed physiographic depiction of the Gulf Coastal Plain Physiographic Region is found in a map entitled "Landforms of the United States" by Raisz (Sixth revised edition, 1957). This map was adapted in the "Physiographic Regions of Mississippi" map published in Childress et al. (1976, p. 23).

Paleozoic Bottoms: In the northeastern part of Tishomingo County, tributaries of the Tennessee and Tombigbee rivers cut through coastal plain sediments of the Tombigbee and Eutaw formations to reveal the hard rocks of the Paleozoic basement. Here, low areas, where Paleozoic rocks are exposed, form the Paleozoic Bottoms Province. Paleozoic rocks are well exposed in Coleman and Tishomingo state parks in Tishomingo County.

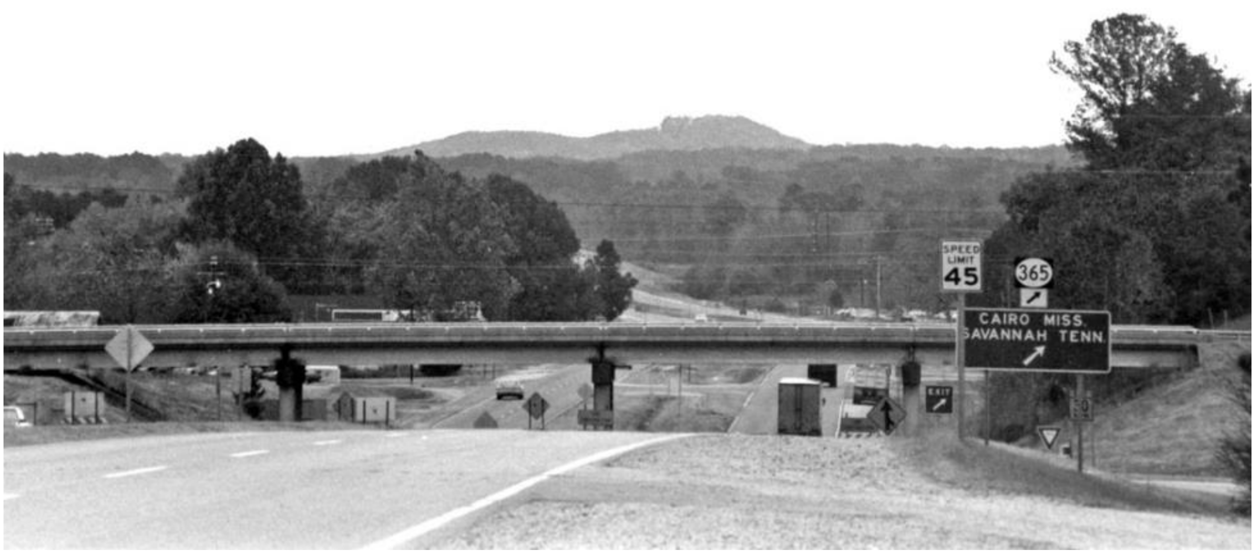


Figure 1. Woodall Mountain in Tishomingo County, Mississippi's highest elevation at 806 feet above sea level, as seen looking southeast from the intersection of Highway 72 and Highway 365 at Burnsville. Picture (scanned print; Image 1448) from Merrill (1988, p. 17).

Figure 2. View from Mt. Woodall to the southwest toward Chestnut Ridge in Tishomingo County, Mississippi. High points on the ridge consist of sands in the Coffee Formation. Picture (slide 4-13; Image 1393) taken in July of 1973.

Figure 3. View from Mt. Woodall to the west. The two unnamed knobby peaks in the distance consist of sands in the Coffee Formation resting above sands in the Eutaw Formation. Picture (slide 4-14; Image 1394) taken in July of 1973.

Tombigbee and Tennessee River Hills: The Tennessee River Hills Physiographic Province consists of hills developed on the unconsolidated Cretaceous sands of the Tuscaloosa, Eutaw, and Coffee formations and form the northern part of the divide separating the Tennessee and Tombigbee drainage basins. The steepest face of the complex cuestas of the Tennessee-Tombigbee divide face eastward toward the Tennessee River. The Coffee Sand has the distinction of capping Woodall Mountain and thus attaining the highest elevation of any geologic unit in the State. Stephenson and Monroe (1940, p.28) considered the Tombigbee Sand to underlie the knob triangulation station on the summit of Woodall Mountain. The Tuscaloosa Formation contains gravel of commercial value. These gravels commonly are reworked within the stream beds of the province. The Tombigbee and Tennessee River Hills were originally forested with pine, oak, and hickory on the hill tops and slopes and in the valleys with black walnut, sycamore, tulip tree, maple, cucumber tree, and an occasional umbrella magnolia in the shaded, rich soils of the valley floor where alder fringed the borders of streams (Lowe, 1915). Mississippi Forestry Commission Publication #76 (undated) combined this region with the Pontotoc Ridge and North Central Hills under the name "Upper Coastal Plain," where it recognized the following commercial tree species: oak, sweet gum, black gum, beech, elm, hickory, yellow poplar, magnolia, sycamore, loblolly pine, shortleaf pine, and longleaf pine.

Black Prairie: Bordering the Tombigbee and Tennessee River Hills on the south and west is the Black Prairie. According to Douglas (2000), the Black Prairie got its name from two distinguishing characteristics: the dark color from the high level of organic matter and the crackling (high shrink-swell) smectite clays that made tree growth difficult. The latter clays are a weathering product of the Cretaceous chalks of the Selma Group, and the physiographic province is an important agricultural region (**figures 4-7**). Both it and the Alluvial Plain of the Mississippi River can easily be recognized in LANDSAT imagery taken from space, such as that of the July 1976 *National Geographic* supplement, Portrait USA. These features are also recognizable on the U.S. Geological Survey Map I-2206 (1991) entitled "Landforms of the Conterminous United States - A Digital Shaded-Relief Portrayal."

The Black Prairie originally consisted of open prairie grasslands with prairie clovers, mellilotus, compass plants, and milk weed; gentle elevations were forested with stunted black jack and post oak (Lowe, 1915). The prairie surface is considerably lower than the eastern hills and slopes southward from 400 feet above sea level in the north, where prairie features are less common, to an altitude of 179 feet at Macon in central Noxubee County (Lowe, 1915), where broad prairie plains are almost continuous.

Changes in land use and vegetation are visible to the highway traveler who crosses onto the Black Prairie. Most notable of these include the change from woodlands to agricultural fields and the presence of cedars along the roadside. Often in clumps of cedars, the white Cretaceous chalks can be seen outcropping below the soil in erosional gullies. This province selectively favors hardwoods over pines, which have a low tolerance for the alka-

Figure 4. Overview of the Black Prairie (Black Belt) on the Natchez Trace. Picture (Kodachrome slide 14-31; Image 1345) taken on May 20, 1976.

Figure 5. Overview of the Black Prairie on the Natchez Trace. Picture (Kodachrome slide 14-30; Image 1344) taken on May 20, 1976.

Figure 6. Cattle grazing on a rich grass field of the Black Prairie Physiographic Province near Artesia in Lowndes County. Here Black Prairie soil is developed on weathered Demopolis Chalk. Picture (digital, CD 51; Image 1054) taken on August 23, 2007.

Figure 7. The Black Prairie on the Demopolis Chalk as viewed from core-hole site #2 at Brooksville, Mississippi. Picture (frame 1/0A; Image 560) taken by Ernest Russell taken in 1989.

line waters of the chalky bedrock. Mississippi Forestry Commission Publication #76 listed the following commercial tree species for the Black Prairie Province: ash, cottonwood, hackberry, red oak, white oak, and sweet gum.

Douglas (2000) questioned if the early European settlers of Alabama founded their towns, such as Montgomery and Selma, on soil boundaries with the towns located on better-drained ultisols next to the alfisols of the "Black Belt," which provided their food crops. Dockery (2002b; and Ground Water section of this publication) suggested the Mississippi towns of Tupelo, Saltillo, Guntown, Baldwin, Frankstown, Booneville, Rienzi, and Corinth were situated on the Coffee Sand aquifer for their water supply, while remaining close to the Black Prairie for their food supply.

Pontotoc Ridge: The Pontotoc Ridge is developed mainly on the sands of the McNairy Sand and Chiwapa Sandstone members of the Ripley Formation but also includes the Owl Creek, and Clayton formations. The ridge tapers to the south where sands of the Ripley and Owl Creek formations grade into chalk. Along its course, the Pontotoc Ridge separates the Black Prairie from the Flatwoods and includes an area of high elevation in the Tippah Hills where the Union/Prentiss County Line abuts Tippah County. North of Highway 30 in western Prentiss County (west of Geeville) Geeville Mountain rises to an elevation of 710 feet; further west, near the Union Coun-

Figure 8. Lebanon Mountain in western Prentiss County, as viewed to the north from Highway 30, is 790 feet above sea level and the second highest hill in Mississippi and is capped by the McNairy Sand. Picture (digital, CD 50; Image 1044) taken on August 9, 2077.

Figure 9. View to the northeast from the Wilcox cuesta on the Natchez Trace Parkway near Little Bear Mountain at Jeff Busby State Park. Picture (slide 4-6; Image 1395) taken in July of 1973.

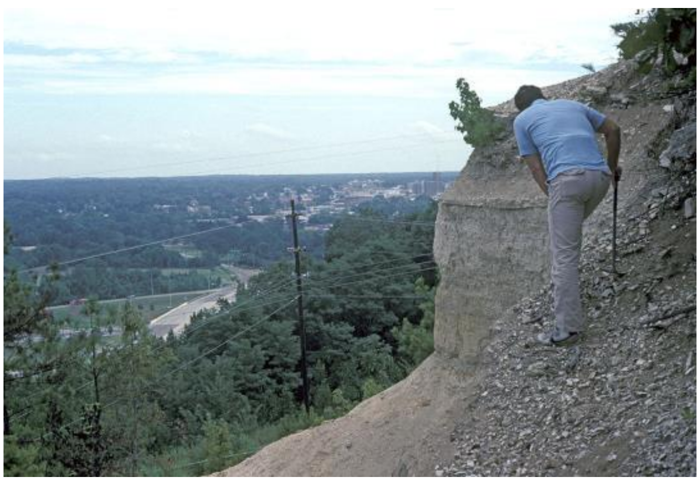


Figure 10. Bill Berggren just above the Meridian-Tallahatta contact on the slope of Mt. Barton, an outlier of the Tallahatta cuesta with a view of Meridian to the north. Picture (slide 203-2; Image 220) taken on August 16, 1988.

Figure 11. View looking west from the Tallahatta Cuesta on old Highway 45 in Lauderdale County at a radio tower south of Meridian, Mississippi. Picture (slide 131-12; Image 214) taken on August 16, 1976.

ty Line, Lebanon Mountain rises to 790 feet in elevation, only 16 feet lower than the state's highest elevation at Woodall Mountain (**Figure 8**). A view from Lebanon Mountain was published by Blake (2006) in *Mississippi Farm Country*. Lowe (1915) noted the backbone of the Pontotoc Ridge to have an average elevation above 500 feet and to divide the waters of the Tombigbee watershed on the east and the Mississippi and Pearl River watersheds on the west. He also noted the region to be one of dense fine hardwood forests. Stephenson and Monroe (1940, p. 29-30) described the Pontotoc Ridge as resting mainly on sandy beds in the Ripley Formation but as also including beds of the Owl Creek, Prairie Bluff, and Clayton formations.

Flatwoods: The Flatwoods is a low, wooded physiographic province developed on the Paleocene Porters Creek Clay. It is a narrow region west of the Pontotoc Ridge, ranging from two to eight miles in width, that is conspicuously lower than the bordering areas (Lowe, 1915). The eastern edge of this province marks the approximate boundary of Cretaceous and Tertiary rocks or the K/T boundary, the level at which the dinosaurs, ammonites, and a host of other things became extinct. Overlying this boundary are sands and limestones of the Clayton Formation followed by the Porters Creek Clay, which is several hundred feet thick. The Porters Creek Clay is used

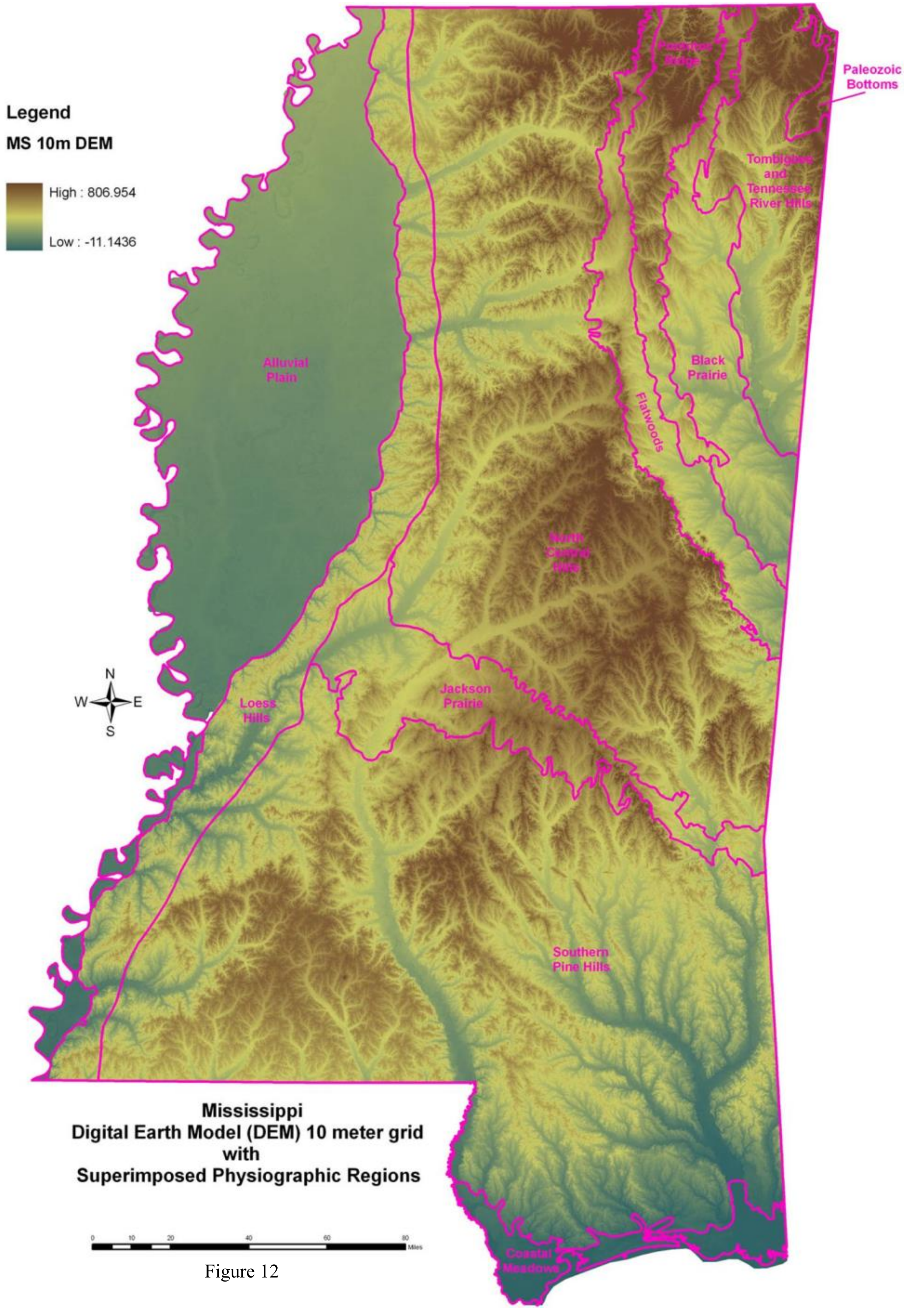

Legend
MS 10m DEM
High : 806.954
Low : -11.1436
Paleozoic Bottoms
and
Tennessee
River Hills
Black Prairie
Flatwoods
Alluvial Plain
N
W
E
S
Loess Hills
Jackson Prairie
Southern Pine Hills
Coastal Meadows
Mississippi
Digital Earth Model (DEM) 10 meter grid
with
Superimposed Physiographic Regions
0
10
20
40
60
80
Miles

Figure 12

Figure 13. View north from the Tallahatta cuesta at Grenada, Mississippi, from a road north of Highway 8 and just east of Interstate 55 (visible at horizon above the road). Picture (color negative 579-22A; Image 577) taken on June 13, 2006.

Figure 14. Duck Hill on Highway 51 in Montgomery County. The hill is an outlier of the Kociusko Formation. Picture (Kodachrome slide 13-8; Image 507) taken in August of 1975.

commercially in Mississippi for the making of kitty litter and in Alabama for the production of light-weight aggregate. Mississippi Forestry Commission Publication #76 listed the following commercial tree species for this region: loblolly pine, shortleaf pine, sweet gum, yellow poplar, red oak, white oak, elm, and hickory.

Foster (1940, p. 9, fig. 1) gave a view of the Flatwoods topography as photographed in 1938 near Sucarnoochee in Kemper County. Conant (1941) gave a view of Flatwoods terrain in Tippah County as seen from Blue Mountain in 1939.

North Central Hills Province: The North Central Hills Province overlies sandy units of the Eocene Claiborne and Eocene-Paleocene Wilcox groups. The eastern edge of this province is marked by the Wilcox cuesta escarpment (**Figure 9**), which is one of the most distinctive topographic features in northeastern Mississippi. Cuestas of the Wilcox Group and the Claiborne Group (**figures 10-14**) continue north into Tennessee and are the recharge areas for some of central and northwestern Mississippi's most important aquifers (ground water sources). These aquifers are also used extensively by the city of Memphis, Tennessee, which boasts having perhaps the nation's best public drinking water.

Lignites are frequently associated with Wilcox and Claiborne deltaic sands and clays and is the reason Lowe (1911) named the region the Northern Lignitic Plateau, though he later changed the name to the North Central Plateau (Lowe, 1915, 1919, 1925). Lowe (1915, p. 31) cited the highest railroad point to be on the Illinois Central Railroad near Holly Springs at 609 feet above sea level.

Jackson Prairie: The Jackson Prairie overlies the Late Eocene marine Yazoo Clay of the Jackson Group and trends east-west across central Mississippi. Hilgard (1860) called this terrain the "hog-wallow prairie region" (**Figure 15**). Sediments of the Jackson Group underlie the Alluvial Plain in northwestern Mississippi and reappear in southeastern Arkansas. A bulge in the Prairie's southwestern margin is produced by the Jackson Dome. Here the Jackson Group is uplifted at Jackson and dips radially from the dome's crest.

The Yazoo Clay is largely composed of montmorillonite, an expansive clay that buckles roads and foundations. It and the underlying Moodys Branch Formation of the Jackson Group are also a source of Late Eocene marine fossils, including the bones of the extinct archaeocete whale *Basilosaurus*. Basilosaur vertebrae are reported to have been used locally as foundation stones. Barone (2005) found 9,998.7 hectares of prairie grassland on the Jackson Prairie in western Mississippi as indicated on land surveys conducted by the U. S. General Land Office in the 1830s; prairie lands were most common in Madison and Rankin counties. Barone (*Ibid*) noted that these grasslands "occurred on calcareous substrates that typically had dry soil conditions that limited tree growth and promoted fires."

The Jackson Prairie is an important agricultural region and is particularly rich where it intersects the loess hills. Here cotton is a major crop. Soils on the Jackson Prairie have a pH almost always higher than 7.5 (in comparison to surrounding forests soils, ranging from

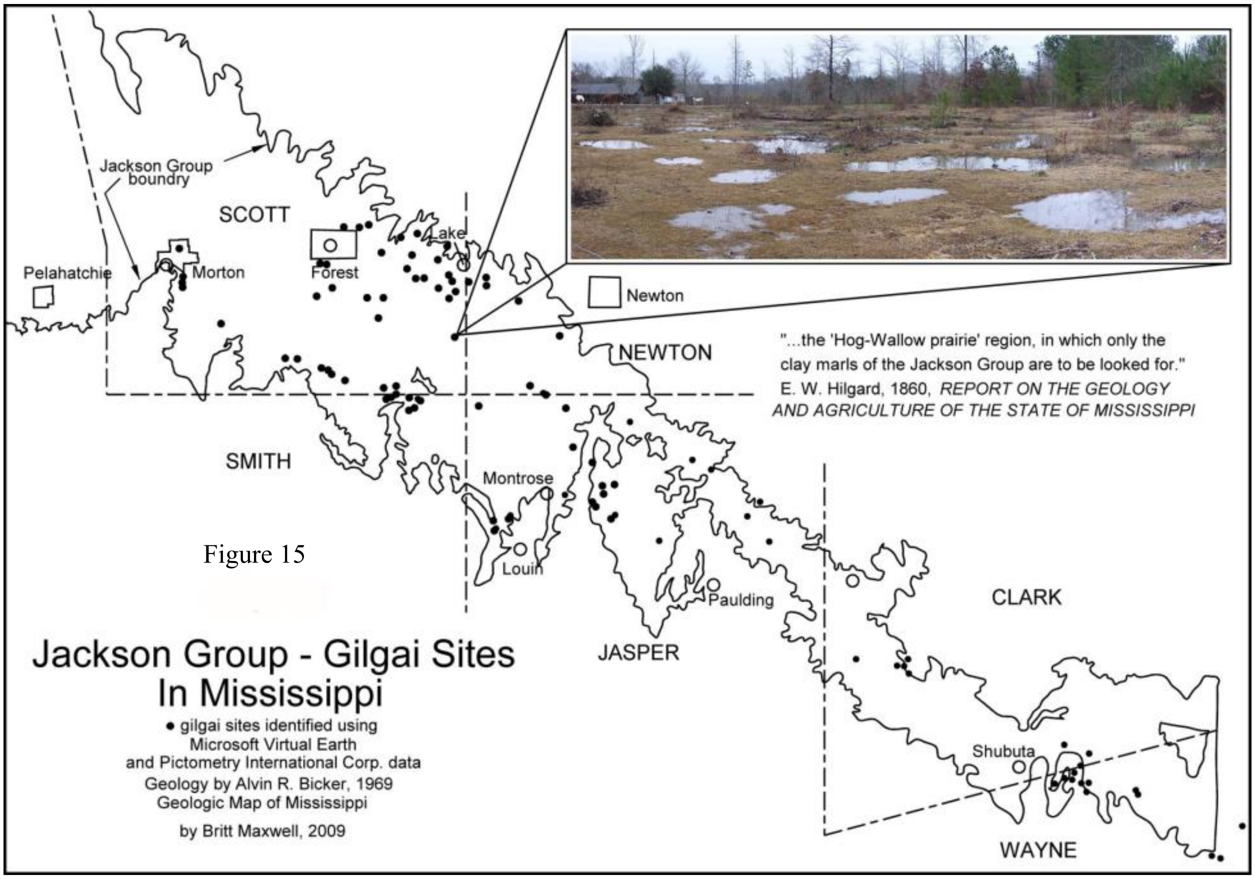


Figure 15

4.0 to 7.0) and support a natural vegetation of the tall grass prairie plants, including big bluestem, little bluestem, yellow Indian grass, and switchgrass, and herbs, including purple prairie coneflower, purple and white prairie clover, black-eyed susan, yellow coneflower, sneezeweed, and numerous asters (Wieland, 1991). Lowe (1915) noted the Jackson Prairie to have a black calcareous prairie soil much like that of the Black Prairie. He gave the original vegetation of much of the prairie as forests of pine, oak, and hickory. Mississippi Forestry Commission Publication #76 listed the following commercial tree species for this region: ash, cottonwood, hackberry, red oak, white oak, and sweet gum.

Along its southern margin the Jackson Prairie is overlapped in numerous places (especially in Jasper County) by sands and gravels of the Citronelle Formation. In these places, the prairie surface is highly elevated with pine forests like those of the Southern Pine Hills Province.

Southern Pine Hills: The Southern Pine Hills Province is a maturely dissected highland underlain by sand and clay units of Miocene to Pliocene age, which produce a noticeable cuesta along the province's northern edge. This highland slopes from elevations above 500 feet in the north and west to about 100 feet along the southern and eastern margins. Capping the highest elevations of this province are the graveliferous sands of the Pliocene Citronelle Formation. The most significant cuesta development is along the northern margin, where sands and sandstones of the Catahoula Formation overlie the Vicksburg Group. South of Jackson this cuesta could be called "radio ridge" as its higher elevations, in an east-west line, are topped with television, radio, and communication towers as well as with water towers (**Figure 16**). The Citronelle Formation and associated high-level terrace deposits (**figures 17-19**) underlie the highest elevations of southern Mississippi and rest disconformably above, from north to south, the Jackson and Vicksburg groups, and the Catahoula, Hattiesburg, Pascagoula, and Graham Ferry formations. These units dip to the south, and their outcrop belts trend east-west parallel to the general coastline of the northern Gulf of Mexico.

Harris (1902, p. 35) illustrated the elevated Citronelle surface of the Southern Pine Hills in his profile of the Illinois Central Railroad from Manchac, Louisiana, to north of Jackson, Mississippi. The highest elevations

Figure 16. Interstate 55 South, south of Byram, Mississippi, at the rise of the Southern Pine Hills Physiographic Province. Along the northern edge of this cuesta are the water towers (left) and radio and communication towers (right) that serve Jackson and central Mississippi. Picture (digital, CD 95; Image 1397) taken on July 2, 2009.

Figure 17. View from terrace deposit at 580 feet west of Cone Hill Church in the NW/4, NW/4, Section 33, T. 5 N., R. 4 E., Rankin County, Mississippi. Terrace sands below contain pebbles composed of Tripoli and no chert pebbles. Picture (slide 384-14; Image 26) taken on September 14, 2004.

Figure 18. James Starnes on road at the surface crest of the Ruth Salt Dome at an elevation of 570 feet above sea level with a view to the east of ridge-forming Citronelle terraces. Picture (color negative 592-2; Image 649) taken on September 11, 2006.

Figure 19. View of Citronelle-capped hills near Turkey Ridge in north-central Jasper County where the Citronelle Formation onlaps the Yazoo Clay. Picture (color negative 560-16; Image 354) taken on November 15, 2005, looding east from a hunting camp dirt road in the SW/4, NE/4, Section 8, T. 3 N., R. 12 E. Ridge in the distance reaches an elevation of 570 feet above sea level.

extended from Magnolia, Mississippi, in the south, where the track was 415 feet above sea level, to Crystal Springs in the north, where the track was 464 feet above sea level. North of Crystal Springs, the grade dropped some 200 feet to 268 feet where the tracks were elevated above the Pearl River flood plain south of Jackson. The town of Summit, Mississippi, just north of McComb in Pike County was so named because it was one of the high points (at 460 feet) between Jackson and New Orleans.

The Southern Pine Hills supported a growing timber industry at the turn of the 20th century. Virgin forests of long-leaf yellow pines were cut for their decay- and insect-resistant heartwood. None of them remain today. However, at one time, these forests contained such large trees and lofty canopies that the forest floors contained little undergrowth and a man could ride through them on horseback at full gallop. Lowe (1911, p 151) showed a stand of such trees. Mississippi Forestry Commission Publication #76 divides this province into the "Thin Loess, Lower Region" some distance west of the Pearl River and the "Lower Coastal Plain Region" just west of the Pearl River and extending below the Jackson

Figure 20. View to the northwest of the Yazoo and Mississippi River floodplains from the Loess Hills in the Vicksburg National Military Park at Vicksburg, Mississippi. Picture (digital, DVD 98, Image 1398) taken on September 26, 2009.

Figure 21. Western edge of the Loess Hills at the Vicksburg National Military Park in Vicksburg, Mississippi. Picture (digital, DVD 98; Image 1399) taken on September 26, 2009.

Prairie to the Alabama state line. The western sector was characterized by the following commercial tree species: loblolly pine, longleaf pine, shortleaf pine, spruce pine, sweet gum, black gum, yellow poplar, red oak, white oak, beech, elm and hickory. The eastern sector was characterized by: longleaf pine, slash pine, loblolly pine, shortleaf pine, spruce pine, oak, sweet gum, black gum, hickory, and swamp tupelo.

B. L. C. Wailes gave the following poetic description of the Southern Pine Hills' virgin forests in an address to Jefferson College dated October 1844: "Extending northward into the interior above the former limits of West Florida the surface becomes higher, more undulating and occasionally quite broken. Here the timber becomes larger, and over considerable tracts the long leaf pine usurps almost exclusive dominion. Straight massive and branchless to near the top, which seems to spread a canopy in the blue ether of the skies, there is a grandeur and majesty in these trees peculiar to such forests alone. Far removed from human habitation, on every side an interminable vista of towering columns is presented broken by no moving object or sign of living thing, whilst the gentle breathing of the winds, through the pinated foliage of the lofty canopy, comes down upon the ear like the distant moaning of a gathering storm filling the lonely traveler with a sense of solitude almost oppressive."

Loess Hills: The Loess Hills Physiographic Province is a rugged terrain that borders the eastern edge of the Mississippi River Alluvial Valley from the Tennessee to the Louisiana state lines. Peculiar to the topography of the Loess Hills are the high vertical stream cuts, which demonstrate the ability of the loess to maintain high wall without significant erosion. It is here during the last ice age that floodplain silts were carried in dust storms by westerly winds to accumulate in thick layers along the eastern valley wall and beyond. This soil can be seen in the vertical highway cuts of the Vicksburg area and elsewhere. It contains the fossil shells of Pleistocene land snails and sometimes the bones of extinct mammals, such as the mastodon.

Mississippi Forestry Commission Publication #76 divides the Loess Hills into the “Thick Loess, Upper Region from Warren and Hinds counties northward and the “Thick Loess, Lower Region” from Claiborne County southward. The upper region was characterized by the following commercial tree species: loblolly pine, shortleaf pine, black gum, red oak, white oak, beech, hickory, and elm. The lower region was characterized by: red oak, white oak, loblolly pine, sweet gum, ash, beech, hackberry, elm, sycamore, and yellow poplar. The Clark Creek Natural Area, a 700-acre tract of land in southwestern Wilkinson County, boasts world record big trees, including Mexican plum and bigleaf snowbell and a state record big hophornbeam.

A vibrant cotton industry grew on the loess soils of Natchez, Mississippi, in the early 1800s and spread to present-day Vicksburg and to the loess belt of northwestern Mississippi and western Tennessee. The loess soil was rich in bases, had silt-sized particles that made water available to plants, plowed easily, and dried up for spring planting. This rich soil attracted settlers to Mississippi from the East. The loess hills out-produced the Delta during most of the antebellum period, and the loess hills cotton of southwestern Mississippi built the mansions of Natchez (Douglas, 2000). The Loess Hills and soil also played an important role in Civil War fortifications (**figures 20-21**) during the 1863 battle of Vicksburg (see the **Vicksburg National Military Park** under the "Loess" section).

Bluff Line Slope Failures and "The Devil's Punch Bowl." Slope failures along the Bluff Line from Yazoo City south to Natchez are common. Logan (1916, p. 65) illustrated: "A Great Slide of Vicksburg Limestone on the River Front Below the Waterworks at Vicksburg." Vestal (1942, p. 14) reported "a special feature" of the Bluff Line in Adams County to be "a number of huge deep hollows or vertical-walled coves, formed by subaerial erosion working in conjunction with ground-water sapping of the underlying sands, producing land slips." He further noted that: "At least one of these, 'The Devil's Punch Bowl,' has recently been well advertised locally." Kane (1947, p. 68) described "The Devil's Punch Bowl," around the turn of the century in 1800, as an awesome phenomenon where: "Far in the past, a great cup-shaped hole, about five hundred feet wide, had formed in the soft earth of the river bluffs." This site "became a spot to be gossiped about, and feared." It was also a site where the bodies of those robbed and murdered by the Mason Gang along the Mississippi River and Natchez Trace were dumped.

The Devil's Punch Bowl near Natchez was the site of Dr. J. L. Riddell's tabloid science-fiction/hoax story entitled "Orrin Lindsay's plan of aerial navigation, with a narrative of his explorations in the higher regions of the atmosphere and his wonderful voyage round the moon," which was published on the front page of the August 13, 1847, issue of *The Southron*, a weekly newspaper printed in Jackson, Mississippi. Riddell's scientific achievements covered the fields of medicine, botany, chemistry, geology, and physics. He was the professor of chemistry at the Medical College of Louisiana in New Orleans (now Tulane University) at the time of "The Devil's Punch Bowl" publication. Later, in 1851 and 1852, he invented and developed the binocular microscope (Riess, 1977; Skinner, 1983).

Alluvial Plain. The Mississippi River Alluvial Plain Physiographic Province, also known as the Yazoo Basin, is the richest agricultural area of Mississippi and has been extensively cleared for the planting of cotton and other crops. It is a flat terrain underlain by over a hundred feet of Mississippi River alluvial sediments, the surface of which slopes from 210 feet above sea level at the Tennessee line to 94 feet at Vicksburg. There is also a gentle eastward slope from the Mississippi River levee and into the Yazoo Basin. Alluvial sediments generally consist of clays and silts in the upper part, which produce vertisols (Douglas, 2000), and sands and gravels in the lower part. The latter comprise the alluvial aquifer, an important groundwater source for crop irrigation and catfish ponds.

Lowe (1915) noted the forest cover of the Alluvial Plain, named as the "Yazoo Delta," to include: red oak, white oak, overcup oak, elm, ash, cypress, red gum, tupelo gum, pecan, hickory, cottonwood, maple, magnolia, beech, basswood, and hackberry, with the red gum and tupelo gum comprising more than 50% of the whole.

Coastal Meadows. The Coastal Meadows was a pine forest in Wailes' day, who described it as follows (1844): "The pine forest commences immediately on the seaboard with a slight margin of live oak sparsely interspersed near the water's edge presenting a very flat surface and being to a considerable extent during the winter rains of a wet miry nature, the timber being generally rather inferior in size but closely set."

Lowe (1915, p. 35) noted the "Kitchen-middens," or shell heaps deposited by Native Americans, at the mouth of the Pascagoula River were often partially submerged and composed almost entirely of freshwater clams at the base, contained brackish-water clams in the middle, and saltwater clams at the top similar to those presently living at the site. This sequence suggested a rise in sea level and partial submergence of the coastal zone.

ECOREGIONS

Ecoregions are a concept utilized by the U.S. Environmental Protection Agency to denote "areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources." At the resolution of ecosystems of "level III" there are only four ecoregions recognized in Mississippi. These are: (1) the Gulf Coastal Plain bedrock areas identified as "65. Southeastern Plains," (2) the Mississippi River Alluvial Plain identified as "73. Mississippi Alluvial Plain," (3) the Loess Hills identified as "74. Mississippi Valley Loess Plains," and (4) the Coastal Meadows identified as "75. Southern Coastal Plain."

Ecoregions at Level IV resolution break out into areas similar to those of the state's physiographic regions (**Figure 22**) and follow the underlying bedrock geology. The following ecoregions are from the "Ecoregions of Mississippi" map published by Chapman et al. (2004) and are listed according to the age of the underlying bedrock (Figure 2.6).

65j. Transition Hills. This region is equivalent to the northeastern part of the Tombigbee and Tennessee River Hills Physiographic Province and is largely underlain by sands and gravels of the Cretaceous Tuscaloosa and Eutaw groups with some streams cutting into Paleozoic rocks of Mississippian age. This region contains some of the highest elevations within the coastal plain and is forested in oak, hickory, and pine with the chestnut oak *(Quercus prinus*) and the Virginia pine (*Pinus virginiana*) representing a distinguishing character of the region.

65i. Fall Line Hills. This region is equivalent to the western and south-central portion of the Tombigbee and Tennessee River Hills and is largely underlain by sands of the Coffee Sand and Eutaw Group. The terrain is one of steep and highly dissected hills with narrow ridge tops and valleys covered in oak, hickory, and pine forests. The shortleaf pine *Pinus echinata* dominates the ridge tops and only small areas are used for pasture or crops. Elevations range mostly from 400 to 700 feet and include the state's highest elevation of 806 at Woodall Mountain.

65b. Flatwoods/Blackland Prairie Margins. This region is a combination of two separated and slightly different north-south trending belts, the Blackland Prairie Margins on the east and the Flatwoods on the west.

Blackland Prairie Margins. The Blackland Prairie Margins Ecoregion is the western portion of the Tombigbee and Tennessee River Hills Physiographic Province and is transitional between the hills to the east and the Black Prairie to the west. In its northern reaches, it overlies the Coffee Sand, and, in its southern reaches, it overlies the Mooreville Chalk. This region contains undulating and irregular plains having more relief than the Flatwoods but having a similar clayey soil with generally poor drainage. The land cover is mostly mixed forest, pasture, and some cropland.

65a. Blackland Prairie. This region is underlain by Cretaceous chalks and marls of the Cretaceous Selma Group, which produce clayey smectitic soils that shrink and swell when dry and wet. The natural vegetation consists of sweetgum (*Liquidamber styraciflua*), post oak (*Quercus stellata*), blackjack oak (*Q. marilandica*), and red cedar (*Juniperus virginiana*), along with patches of bluestem prairie. Today the area is mostly cropland and pasture with some pond-raised catfish.

65b. Flatwoods. This region is equivalent to the Flatwoods Physiographic Province and consists of forested plains or lowlands with little relief formed on the Paleocene Porters Creek Clay.

65e. Northern Hilly Gulf Coastal Plain. This region extends north to the Kentucky-Tennessee border, but represents two different and separated north-south trending physiographic regions in Mississippi, including the Pontotoc Ridge on the east and the northern portion of the North Central Hills on the west. The U.S. EPA did not recognize the Pontotoc Ridge as a separate ecoregion in Mississippi because it was not recognized as such in Tennessee, and mapping units were designed to be contiguous across state lines. The Pontotoc Ridge overlies marls and sands of the Ripley Cuesta where soils have a reddish color. West of the Flatwoods, the ecoregion overlies sandy strata of the Tertiary upper Midway, Wilcox, and Claiborne groups. The distinguishing character between the Northern and Southern Gulf Coastal Plain is a cooler climate in the north and a greater density of upland hardwood forests than in the south. The boundary between these ecoregions is an east-west line approximately along the coarse of the Yalobusha River and just north of the divide separating tributaries of the Yazoo River Basin to the north and the tributaries of the Big Black River to the south. This line follows the east-west boundary between the "North Central Plateau" and "South Central" forest regions of Dunston (1910, p. 6). Dunston (*Ibid*, p. 28) noted the chief difference between these regions as follows: "The north central plateau is an old agricultural section, while a large part of the south central region is covered with forest growth and has never been in cultivation."

65d. Southern Hilly Gulf Coastal Plain. This region includes the southern extent of the North Central Hills Physiographic Province and the northern extent of the Southern Pine Hills with the exclusion of the Jackson Prairie in between. The Southern Hilly Gulf Coastal Plain extends into the western edge of Georgia and contains cuestas of higher elevation founded on sandy units of Paleocene, Eocene, Oligocene, and Miocene age as well as the upland Pliocene sands and gravels of the Citronelle Formation along its southern margin. This region has a warmer climate and more pines than the Northern Hilly Gulf

Coastal Plain. It grades from a mostly oak-hickory-pine forest in the north into a mixed forest and longleaf pine forest in the south. Land cover is mostly forest with pasture and some cropland.

65q. Buhrstone/Lime Hills. This region includes the Tallahatta and Lisbon cuestas and the Jackson and Vicksburg limestone terrains in Alabama. In Mississippi, it is largely restricted to the Tallahatta Cuesta in the southern extent of its range. This cuesta forms a rugged, north-facing escarpment with well-drained and sandy soils. Streams have a higher gradient and rocky bottoms in this region.

65r. Jackson Prairie. This region is much the same as the physiographic province of the same name and consists of a narrow belt of irregular plains and broad hills developed on the Late Eocene Yazoo Clay. This calcareous clay produces alkaline clayey soils that shrink and swell when dry and wet. Historic vegetation includes mostly mixed hardwood and pine forest with a scattering of prairies. Today much of the region is forested in pine plantations with some pastures and row crops.

65f. Southern Pine Plains and Hills. This region includes the southern extent of the Southern Pine Hills Physiographic Region, extends across southern Mississippi and Alabama, and covers what was once part of the longleaf pine belt. Almost all the original heartwood pine forests are now gone and replaced by slash and loblolly pine plantations. Endangered species of the region include the red-cockaded woodpecker, gopher tortoise, eastern indigo snake, and black pine snake. Bedrock units consist of Miocene sands and clays with the Pliocene sands and gravels of the Citronelle Formation occupying the higher elevations. Streams of the region tend to be tannin-rich, dark-tea in color, and more acidic than these of the Southern Hilly Gulf Coastal Plain.

65p. Southeastern Floodplains and Low Terraces. This region includes the flood plains and terraces of the Tombigbee, Pearl, and Pascagoula/Leaf/Chickasawhay rivers. These riverine ecoregions contain swamps and oxbow lakes and forests of bald cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), and oak-dominated hardwood bottomlands. Low terraces are forested, with some utilized for pasture or cropland.

73a. Northern Holocene Meander Belts. This region contains the meander belt of the present course of the Mississippi River and the abandoned channels of previous courses, including point bars, oxbows, natural levees, and abandoned channel environments. The meander belt is an alluvial ridge that is elevated above the more distant floodplain and back swamps. Natural levees are the most conspicuous landform, and the alluvial soils tend to be loamy. The original hardwood forests have been removed from this region to make way for cropland, with cotton as the primary crop.

73b. Northern Pleistocene Valley Trains. This region is made up of braided-stream alluvium from Pleistocene glacial outwash deposits carried by the Mississippi and Ohio Rivers. Valley train deposits make up about 54% of the entire Mississippi River Alluvial Plain but comprise a smaller area of the Alluvial Plain/Yazoo River basin in Mississippi, where they were largely eroded away in Holocene times. Here remnant valley train landscapes are of Late Wisconsin age, dating some 10,000 to 20,000 years before the present, and the land is at or slightly higher than the Holocene Alluvial Plain. The original hardwood forests have been largely replaced by cropland of soybeans and some cotton.

73d. Northern Back Swamps. This region consists of poorly drained floodplain and wetland depressions with clayey organic-rich soils. Forested hardwood bottomlands are more prevalent than in the adjacent meander belts, with cypress and tupelo in the wetter areas, but much of the land has been drained for pasture lands and catfish ponds.

73k. Southern Holocene Meander Belts. This region extends from just north of Natchez, Mississippi, to south of New Orleans, Louisiana. It is like the meander belts to the north but has a longer growing season and more precipitation. Bottomlands have been largely cleared for cropland, and the levee system is extensive.

73m. Southern Backswamps. This region is like the backswamps to the north but has a warmer climate and more precipitation.

74a. Bluff Hills. This region consists of Tertiary bedrock and graveliferous pre-loess terrace deposits capped by a thick layer of loess, often greater that 50 feet in thickness. Waterfalls are common along the Bluff Hills, such as where the Glendon Limestone is present around and north of Vicksburg and siliceous sandstones are present at Clark Creek in Wilkinson County and elsewhere. Here stream gradients cut through rock ledges and drop abruptly to the level of the Mississippi River Alluvial Plain. The Bluff Hills have steeper slopes, are more dissected, and are generally more forested than the Loess Plains to the east.

Ecoregions of Mississippi

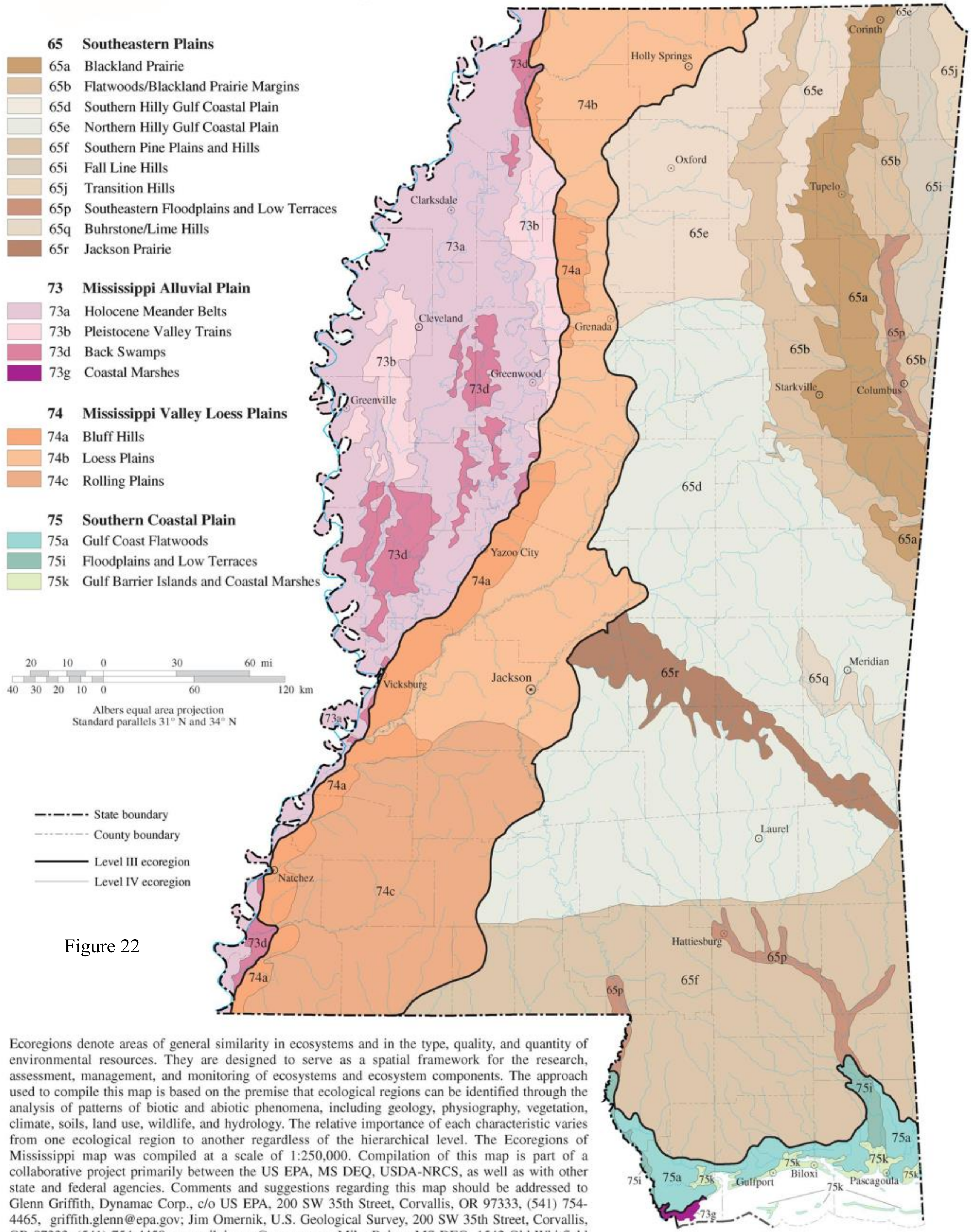


Figure 22

Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. They are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. The approach used to compile this map is based on the premise that ecological regions can be identified through the analysis of patterns of biotic and abiotic phenomena, including geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. The relative importance of each characteristic varies from one ecological region to another regardless of the hierarchical level. The Ecoregions of Mississippi map was compiled at a scale of 1:250,000. Compilation of this map is part of a collaborative project primarily between the US EPA, MS DEQ, USDA-NRCS, as well as with other state and federal agencies. Comments and suggestions regarding this map should be addressed to Glenn Griffith, Dynamac Corp., c/o US EPA, 200 SW 35th Street, Corvallis, OR 97333, (541) 754-4465, griffith.glenn@epa.gov; Jim Omernik, U.S. Geological Survey, 200 SW 35th Street, Corvallis, OR 97333, (541) 754-4458, omernik.james@epa.gov; or Mike Beiser, MS DEQ, 1542 Old Whitfield Road, Pearl, MS 39208, (601) 664-3959, mike_beiser@deq.state.ms.us.

The natural forests of the region are of the oak-hickory type but also include beech, sugar maple, sweetgum, basswood, eastern hophornbeam, and tulip poplar. Forests in the southern reaches of the region contain more southern magnolia, water oak, and Spanish moss. The Bluff Hills are a place of landslides and ongoing erosion where slopes lack adequate vegetation.

74b. Loess Plains. This region consists of rolling hills and a thinner layer of loess, which often rest directly above Tertiary bedrock in areas where the pre-loess terrace deposits are absent. It was once the most highly productive agricultural area in Mississippi, but now many areas are planted in pines or have reverted to a mixed forest landscape. Streams and rivers tend to have a low gradient and are sediment-filled in the downstream reaches due to past cultivation and erosion.

74c. Southern Rolling Plains. The loess cover of this region drapes an irregular and dissected topography developed above sands and clay of Miocene age and, at higher elevations, graveliferous sands of the Pliocene Citronelle Formation. The region has a warmer climate and greater rainfall than the Loess Plains to the north. The land cover is largely pine plantations or loblolly and shortleaf pine forests having a higher pine concentration than in the Bluff Hills or Loess Plains to the north.

75. Southern Coastal Plain. This level III region extends from South Carolina and Georgia through central Florida and along the Gulf Coastal lowlands of the Florida Panhandle, Alabama, and Mississippi. Level IV regions include the Quaternary terraces and delta deposits of the **Gulf Coast Flatwoods (75a)**, the riverine ecoregions of the **Floodplains and Low Terraces (75i)**, and the **Gulf Barrier Islands and Coastal Marshes (75k)**.

SURFACE ELEVATIONS AND RIVER BASINS

Mississippi ranks fourth as the flattest of the 50 states, ranging from sea level on the coast to 806 feet above sea level on the summit of Woodall Mountain in Tishomingo County. The next flattest states include Louisiana (535 feet above sea level at Driskill Mountain in Bienville Parish to 8 feet below sea level in New Orleans), Delaware (448 feet above sea level on Ebright Road at the Pennsylvania State Line to sea level), and Florida (345 feet above sea level at Britton Hill in Walton County to sea level) (data modified from Van Zandt, 1976, p. 174-175). However, the difference between a state's highest and lowest elevations is just one measure of relief. Along the eastern side of the state, the line connecting Woodall Mountain to the coast runs almost the entire length of the state. However, this line is not a gradual slope, but a profile highly dissected by the Tombigbee River Valley in the north and the Chunky-Chickasawhay-Pascagoula river valleys in the south (Figure 22). On the western side of the state, one of the highest elevations on the Illinois Central Railroad is not in the north but in the south at the Town of Summit in Pike County, Mississippi.

Mississippi owes its existence as dry land in part to regional uplift of the coastal plain and in part to the present lowstand in sea level. Williams and Ferrigno (1999) estimated that global sea level would rise by 80.44 meters or 264 feet if the world's ice sheets and glaciers melted. A sea level rise of this magnitude would flood coastal Mississippi, the Mississippi "Delta," the Big Black River Valley to the town of West in northwestern Holmes County, and the Pearl River Valley to Jackson. In the Tombigbee River Valley, a sea-level rise of 264 feet would flood Columbus, West Point, Aberdeen, and Amory and place Starkville on beach-front property (Dockery and Mason, 2002). While most of the world's glacial ice is stored in Antarctica, Schlermeier (2004) predicted a sea-level rise of seven meters (23 feet) if Greenland's ice sheet were to melt.

Ten counties in Mississippi have elevations greater than 700 feet above sea level; the six highest are contiguous counties in the northeastern corner of the state and the next four highest are contiguous counties in central Mississippi. In order of highest to lowest, these include: (1) Tishomingo County with a maximum elevation at 806 feet above sea level, (2) Prentiss County at 791 feet, (3) Tippah County at 787 feet, (4) Alcorn County at 785 feet, (5) Benton County at 769 feet, (6) Union County at 760 feet, (7) Choctaw County at 726 feet, (8) Winston County at 720 feet, (9) Attala County at 720 feet, and (10) Neshoba County at 708 feet.

The most rugged Mississippi counties, those with a relief of 500 feet or more, include, in descending order of relief: (1) Kemper County with lowest and highest elevations of 116 to 662 feet above sea level and a relief of 546 feet, (2) Noxubee County with lowest and highest elevations of 104 to 643 feet and a relief of 539 feet, (3) Attala County with lowest and highest elevations of 205 to 720 feet and a relief of 515 feet, (4) Lauderdale County with lowest and highest elevations of 159 to 669 feet and a relief of 510 feet, (5) Prentiss County with lowest and highest elevations of 288 to 791 feet and a relief of 503 feet, and (6) Jefferson County with lowest and highest elevations of 23 to 524 feet and a relief of 501 feet. With the exceptions of Jefferson County, which extends from the high Citronelle plateau to the Mississippi River, and Attala County, which contains the divide between the Big Black and Pearl River flood plains, the other counties straddle the Wilcox cuesta and the eastern divide of the Tombigbee River Drainage Basin.

The "Did You Know That" section of the May 1955 issue of the *Mississippi Geological Society Bulletin* states: Some tributaries of the Big Black River are rapidly cutting back into the Pearl River drainage basin. The divide between the two systems is only a mile northwest of the Pearl River, a few miles northeast of Jackson." Priddy (1960, p. 28) noted the Big Black-Pearl River divide to be "one of the most unusual physiographic features in Madison County." Here the divide is so close to the Pearl River on the county's eastern boundary that 95% of the county's drainage flows northwest to the Big Black River on the county's western boundary. The 25 creeks that cross the Natchez Trace before entering the Pearl River lowland are so short that they have no names. Priddy also noted that the lowlands of the Big Black River were 75 to 100 feet lower than those of the Pearl, making it seem the capture of the Pearl River by the tributaries of the Big Black River to be imminent.

The flattest counties in Mississippi are eight counties within the Mississippi River Alluvial Plain and include, beginning with the flattest up: (1) Quitman County with lowest and highest elevations of 135 to 186 feet above sea level and a relief of 51 feet, (2) Leflore County with lowest and highest elevations of 92 to 155 feet and a relief of 63 feet, (3) Humphreys County with lowest and highest elevations of 75 to 141 feet and a relief of 66 feet, (4) Sunflower County with lowest and highest elevations of 80 to 152 feet and a relief of 72 feet, (5) Issaquena County with lowest and highest elevations of 53 to 139 feet and a relief of 86 feet, (6) Washington County with lowest and highest elevations of 74 to 165 feet and a relief of 91 feet, (7) Bolivar County with lowest and highest elevations of 98 and 191 feet and a relief of 93 feet, and (8) Coahoma County with lowest and highest elevations of 116 to 212 feet and a relief of 96 feet. Should all the ice in Antarctica and Greenland melt due to global warming, these counties would be completely covered by the 264-foot rise in sea level to water depths ranging from 50 to 210 feet below sea level. The data for county elevations used here came from the 10-meter Digital Elevation Model constructed by Mississippi Automated Resource Information Systems (MARIS) in 2004.

Van Zandt (1976, p. 105-106) gave the history of the state's boundaries, from the authorization of the Mississippi Territory by Congress on April 7, 1798, to a Supreme Court ruling on February 26, 1974, concerning the Luna Bar accretion caused by the westward movement of the Mississippi River. Van Zandt (*Ibid*, p. 171) placed the geographic center of Mississippi in Leake County "9 miles west-northwest of Carthage."

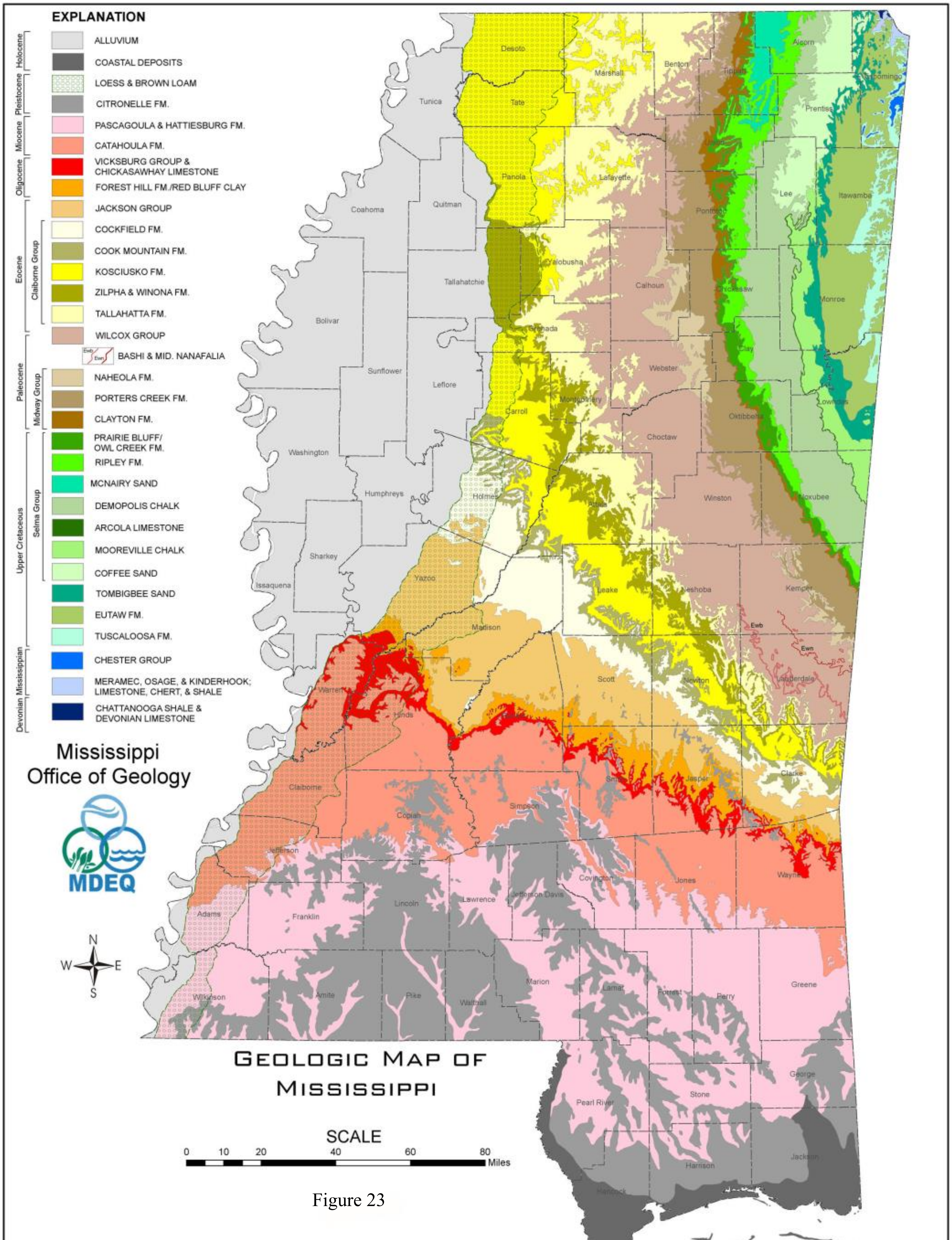
SURFACE GEOLOGY

The surface geology of Mississippi shows the strong influence of the Mississippi Embayment and the Gulf of Mexico Basin on the orientation of outcropping formations within the state. Eocene, Paleocene, and Cretaceous formations in the northern part of the state have a north-south trending outcrop belt, reflecting their location on the eastern flank of the Mississippi Embayment. Late Eocene, Oligocene, Miocene, and Pliocene formations in southern Mississippi have outcrop belts trending from east-southeast to west-northwest, reflecting the greater influence of the Gulf of Mexico Basin.

Unconformably overlying the Late Eocene-Pliocene section in southern Mississippi are the high-level, coast-parallel terraces and graveliferous terrace deposits of the Citronelle Formation. The Pleistocene loess belt of western Mississippi runs north-south at the margin of the Mississippi River Alluvial Plain. Beneath the loess are pre-loess terrace sands and gravels of the mid-Pleistocene Mississippi-Ohio river systems, which are now perched along the Mississippi River's valley wall.

Paleozoic rocks of Devonian to Mississippian age are exposed only in the northeastern-most reaches of Mississippi. These outcrops occur along Pickwick Lake, at the Bay Springs Lock and Dam, and along the Bear Creek drainage area in and around Tishomingo State Park.

The Geologic Map of Mississippi in **Figure 23** is a revision using element from both the 1945 and 1969 editions of the state map at the 1:500,000 scale. The state geologic map is undergoing another revision as the state is being remapped at the site specific scale of 7.5-minute topographic quadrangle geology maps, a scale of 1:24,000. **Figure 34** shows the status of this work as of September 2018. Maps shown as numbered Open File Reports are available as paper copies and as digital files from MGEQ's Office of Geology website.



EXPLANATION
Holocene
ALLUVIUM
COASTAL DEPOSITS
Pleistocene
LOESS & BROWN LOAM
CITRONELLE FM.
Miocene
PASCAGOULA & HATTIESBURG FM.
CATAHOULA FM.
Oligocene
VICKSBURG GROUP & CHICKASAWHAY LIMESTONE
FOREST HILL FM./RED BLUFF CLAY
Eocene
JACKSON GROUP
Claiborne Group
COCKFIELD FM.
COOK MOUNTAIN FM.
KOSCIUSKO FM.
ZILPHA & WINONA FM.
TALLAHATTA FM.
WILCOX GROUP
BASHI & MID. NANAFALIA
Paleocene
Midway Group
NAHEOLA FM.
PORTERS CREEK FM.
CLAYTON FM.
Upper Cretaceous
Selma Group
PRAIRIE BLUFF/ OWL CREEK FM.
RIPLEY FM.
MCNAIRY SAND
DEMOPOLIS CHALK
ARCOLA LIMESTONE
MOOREVILLE CHALK
COFFEE SAND
TOMBIGBEE SAND
EUTAW FM.
TUSCALOOSA FM.
Devonian Mississippian
CHESTER GROUP
MERAMEC, OSAGE, & KINDERHOOK; LIMESTONE, CHERT, & SHALE
CHATTANOOGA SHALE & DEVONIAN LIMESTONE
Mississippi
Office of Geology
MDEQ
N
W
E
S
GEOLOGIC MAP OF
MISSISSIPPI
SCALE
0 10 20 40 60 80
Miles

Figure 23

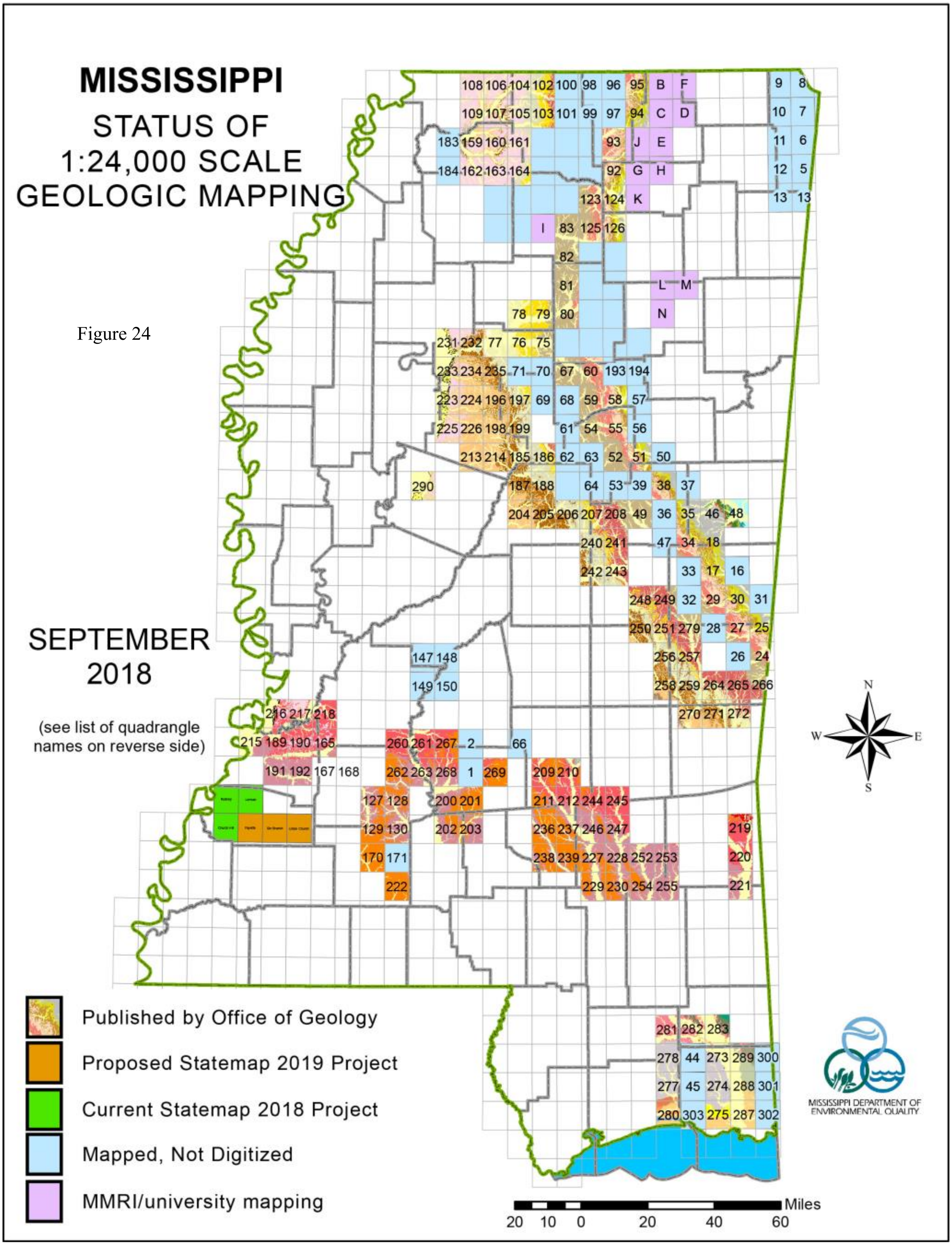

MISSISSIPPI
STATUS OF
1:24,000 SCALE
GEOLOGIC MAPPING
SEPTEMBER
2018
(see list of quadrangle
names on reverse side)
Published by Office of Geology
Proposed Statemap 2019 Project
Current Statemap 2018 Project
Mapped, Not Digitized
MMRI/university mapping
Miles
20 10 0 20 40 60
N
S
E
W
MISSISSIPPI DEPARTMENT OF
ENVIRONMENTAL QUALITY

Figure 24

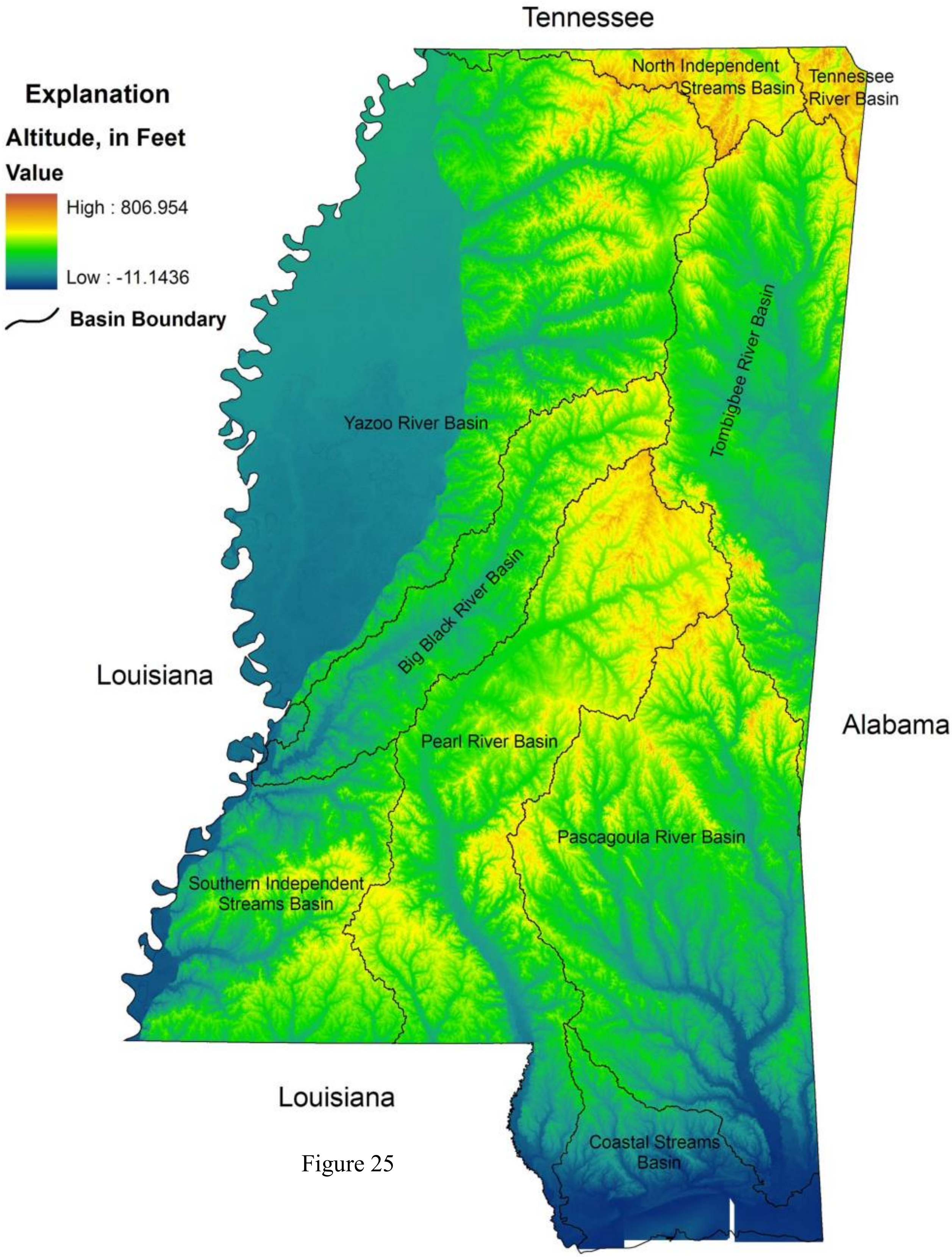


Figure 25

The Major River Basins of Mississippi

MISSISSIPPI'S RIVER BASIN GEOLOGY

David T. Dockery III, RPG, and Barbara Yassin, from the November 2017 issue of *Environmental News* (volume 14, issue 10, pages 9-12).

The bedrock geology of Mississippi is a controlling factor in the distribution of soil types, physiographic provinces, ecoregions, and river basins in the state. **Figure 26** is a graphic depiction of cuestas in the Gulf Coastal Plain from Nevin Fenneman's (1938) *Physiography of Eastern United States*. Cuesta is a Spanish word for "flank or slope of a hill;" in geology it specifically refers to outcrop belts that form a gentle slope down structural dip (in Mississippi to the west and south) and a steep opposing slope where strata are eroded in their up-dip limits. In Mississippi, the steep slopes of the Wilcox Cuesta face the Tombigbee River Basin. The cross section of **Figure 26** is representative of the geology along the Mississippi-Alabama state line from Tennessee to the Gulf Coast. The two highest hills in Mississippi are Woodall Mountain (806 feet above mean sea level) on the Fall Line Hills Cuesta in the Tennessee River Basin and Mt. Lebanon (790 feet) on the Ripley Cuesta (Pontotoc Ridge) in the North Independent Streams Basin. Prairie low lands such as the Black Belt, Flatwoods, and Jackson Prairie develop on chalk and/or clay strata with low permeability and soils that do not support steep slopes and are more prone to erosion due to increased runoff.

Figure 25 is a relief map of Mississippi with the divides of major river basins. The five largest river basins in order of rank include the Yazoo River Basin, draining 13,355 square miles within the state, the Pascagoula River Basin at 9,600 square miles, the Pearl River Basin at 8,700 square miles, the Tombigbee River Basin at 6,100 square miles, and the Big Black River Basin at 3,400 square miles. The divide between the Tombigbee River Basin and the basins of the Pascagoula, Pearl, and Big Black rivers is a ridge of high ground in elevation-coded colors of dark green and white with white creating a snowcapped appearance to the highest elevations. This high ground drops to mid-level light-green-coded elevations along the divide of the Tombigbee and Yazoo river basins before rising northward to white elevations along a ridge known as the Pontotoc Ridge extending southward from the North Independent Streams Basin. Across the low saddle, the divide jumps from the Paleocene Wilcox Cuesta across strata to the Cretaceous Ripley/McNairy Sand Cuesta. The low divide is associated with the curious fact that flood plains of the Yazoo and Tombigbee river basins in northern Mississippi are lower in elevation than the Big Black, Pearl, and Pascagoula in central Mississippi.

Figure 27 is a composite Mississippi map depicting surface geology, hillshade relief, and major river basins. Labelled on the map is the location of Little Mountain in Jeff Busby Park on the Natchez Trace Parkway, a road that follows the divide of the Big Black and Pearl Riv-

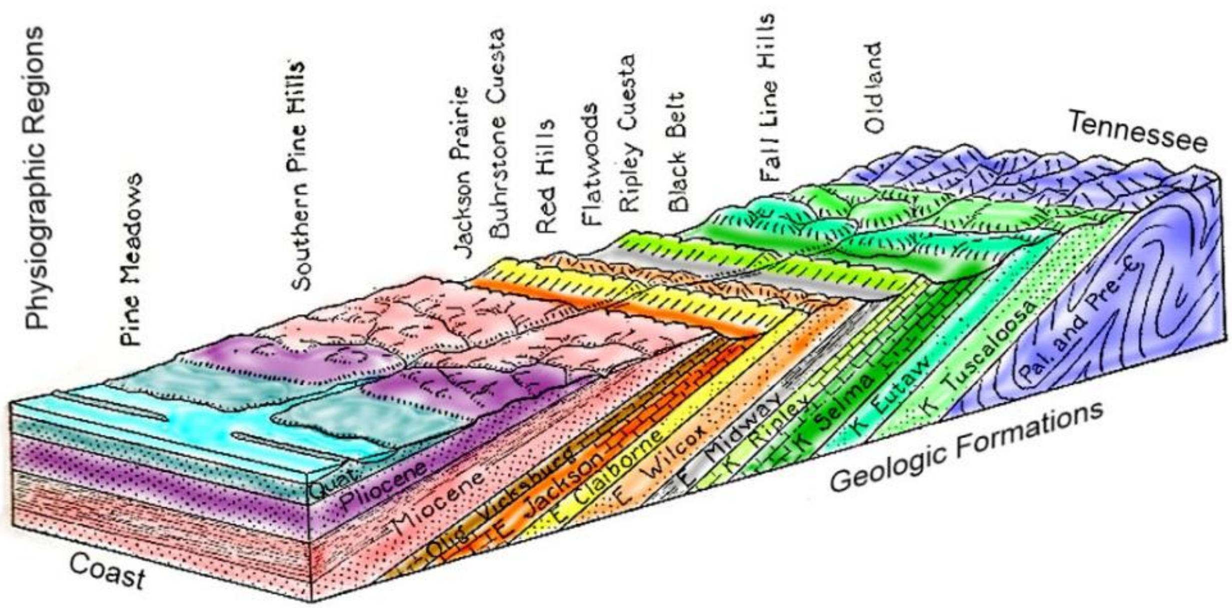


Figure 26. Cuestas in the Gulf Coastal Plain from Fenneman (1938).

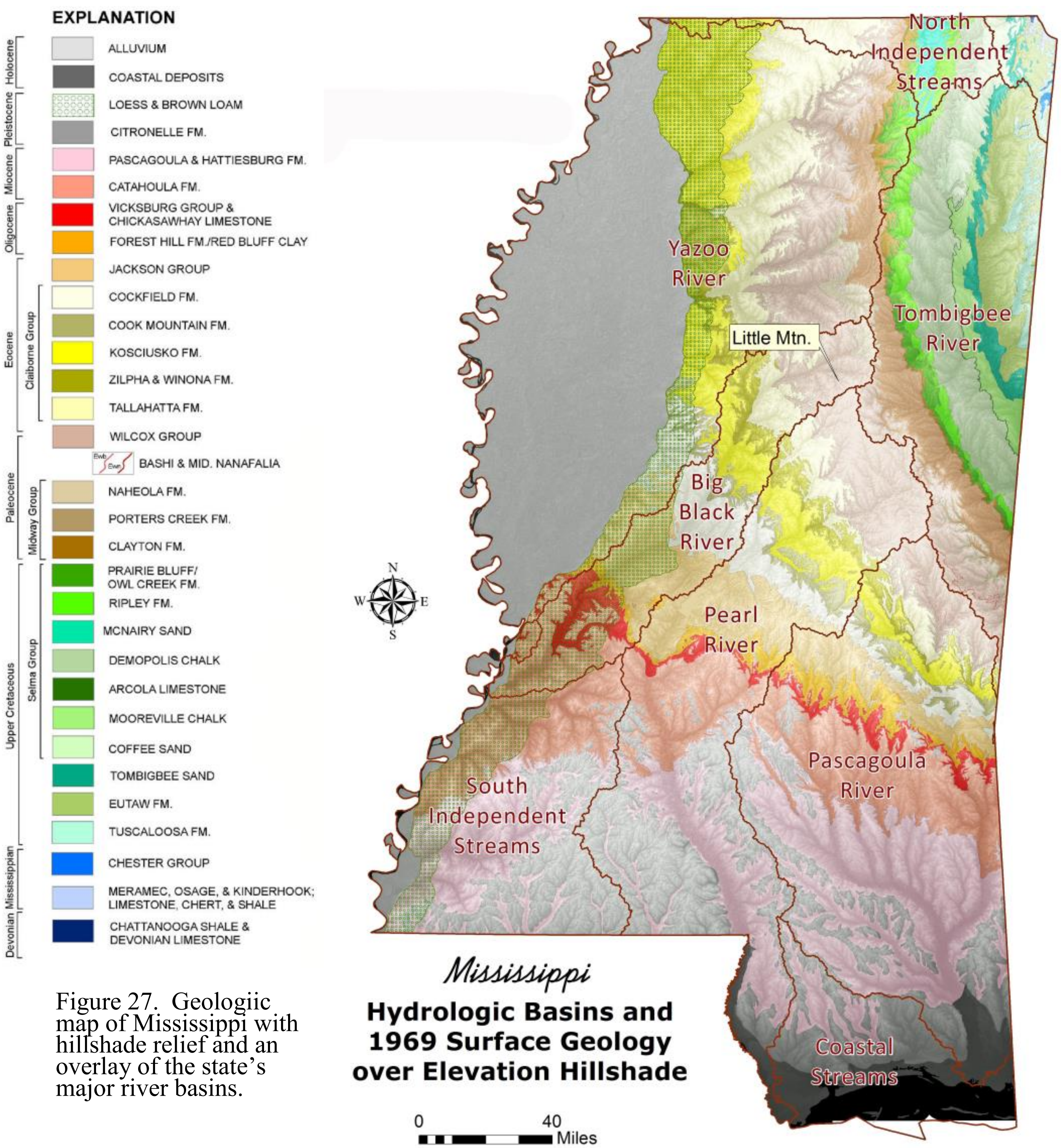


Figure 27. Geologiic map of Mississippi with hillshade relief and an overlay of the state's major river basins.

er divide northward to that point. Little Mountain (**Figure 28**) is an outlier of the high ground of the Wilcox Cuesta at the triple basin junction of the Big Black, Pearl, and Tombigbee river basins. The low elevations of the Tombigbee River Basin are on the soils of the Black Belt (**Figure 27**), soils that develop from easily weathered chalks and marls in the Selma Group. **Figure 29** is a LiDAR bare earth hillshade relief image showing rugged terrain along the western margin of the Tombigbee River Basin and at the triple basin junction with the Pearl and Big Black river basins. In the east, the Tombigbee River Basin is characterized by low prairie land; in the west, the upper Pearl and Big Black river basins are characterized by higher elevations and greater relief. This varied terrain correlates with the varied bedrock geology beneath it.

Figure 28. View to the northeast from the Wilcox Cuesta at Liitle Mountain in Jeff Busby Park on the Natchez Trace Parkway in the upper reaches of the Big Black River Basin. Picture was taken in July of 1973.

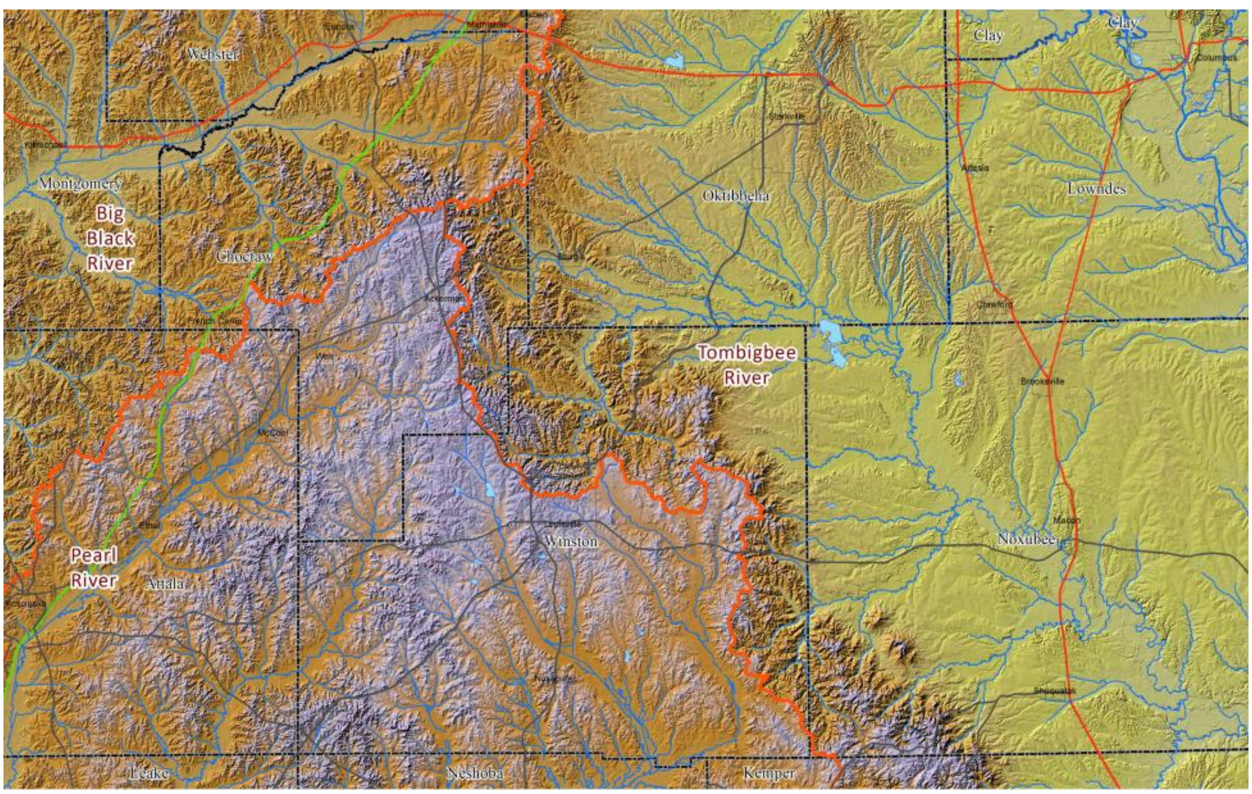


Figure 29. LiDAR bare earth hillshade relief map showing the triple baskin junction of the Tombigbee River Basin (east) and the Pearl and Big Black river basins (west). The Natchez Trace Parkway is in green. Elevations are coded with golden yellow for low, brown for intermediate, and lavender fo high.

STREAM CAPTURE

David T. Dockery III, RPG, and Barbara Yassin, from the December 2018 issue of *Environmental News* (volume 15, issue 10).

Stream capture, also known as river capture, river piracy, or stream piracy, is a geomorphological phenomenon where a stream is diverted from its own bed to flow down the bed of a neighboring stream. **Figure 30** from Wikipedia is an illustration of one stream capturing another by headward erosion. Once erosion cuts through the stream basin divide, the stream of the higher valley flows into the stream of the lower valley, abandoning its downstream course. This is the potential scenario playing out along the western shore of the Ross Barnett Reservoir, where eastward eroding tributaries of the Big Black River are reaching a low narrow divide with the Pearl River Basin and where the Pearl River floodplain hugs its western basin margin. An erosional breakthrough here would capture the Upper Pearl River and add its water shed to that of the Big Black River Basin. As the Big Black River floodplain is a hundred feet lower than that of the Pearl River, it would also reverse water flow along the abandoned downstream channel. Even so, the precarious Big Black-Pearl River divide has been stable over historic time and is in no immediate danger of failing.

Figure 31 shows tributaries of the Big Black River against the divide's western margin. The red line (Profile A-A') in figures 2 and 3 is a distance of about 1,800 feet between Reservoir's western shore at 294 feet above mean seas level and the 294-foot contour on the western side of the divide. The 294-foot contour line in **Figure 32** separates the divide ridge from areas west of the divide that are lower than the Reservoir pool level. The crest of this divide as shown in **Figure 33** is only fifty feet higher than the pool level. This narrow low isthmus is all that keeps the Big Black and Pearl River Basins in place.

Stream capture has played an important role in creating the present landscape of our state. Even river basins are not permanent. One evidence of this is the river sands and gravels that now cap the highest elevations of southern Mississippi and elsewhere, a complete reversal from river bottom to river divide and high plateau.

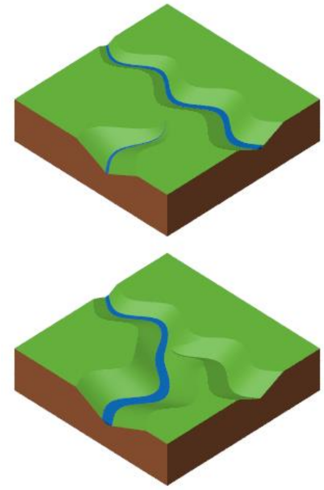


Figure 30. Steam capture by headward erosion (Wikipedia).

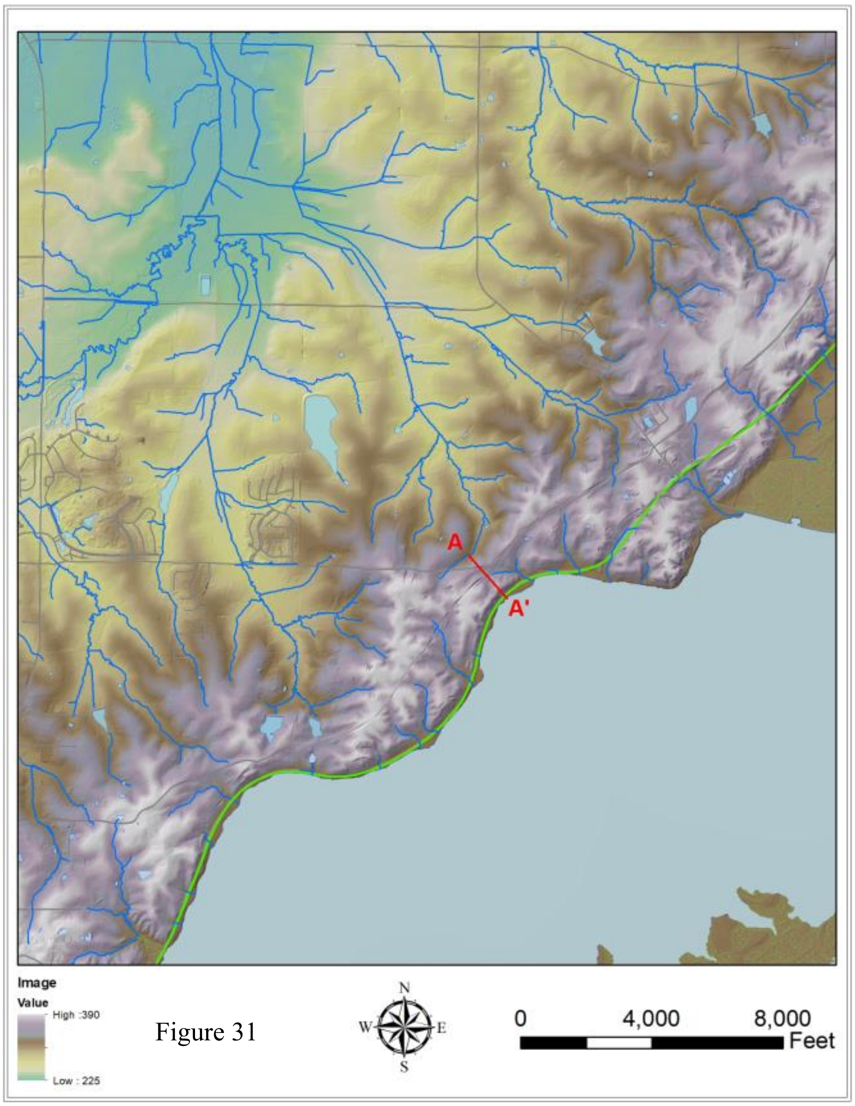


Figure 31

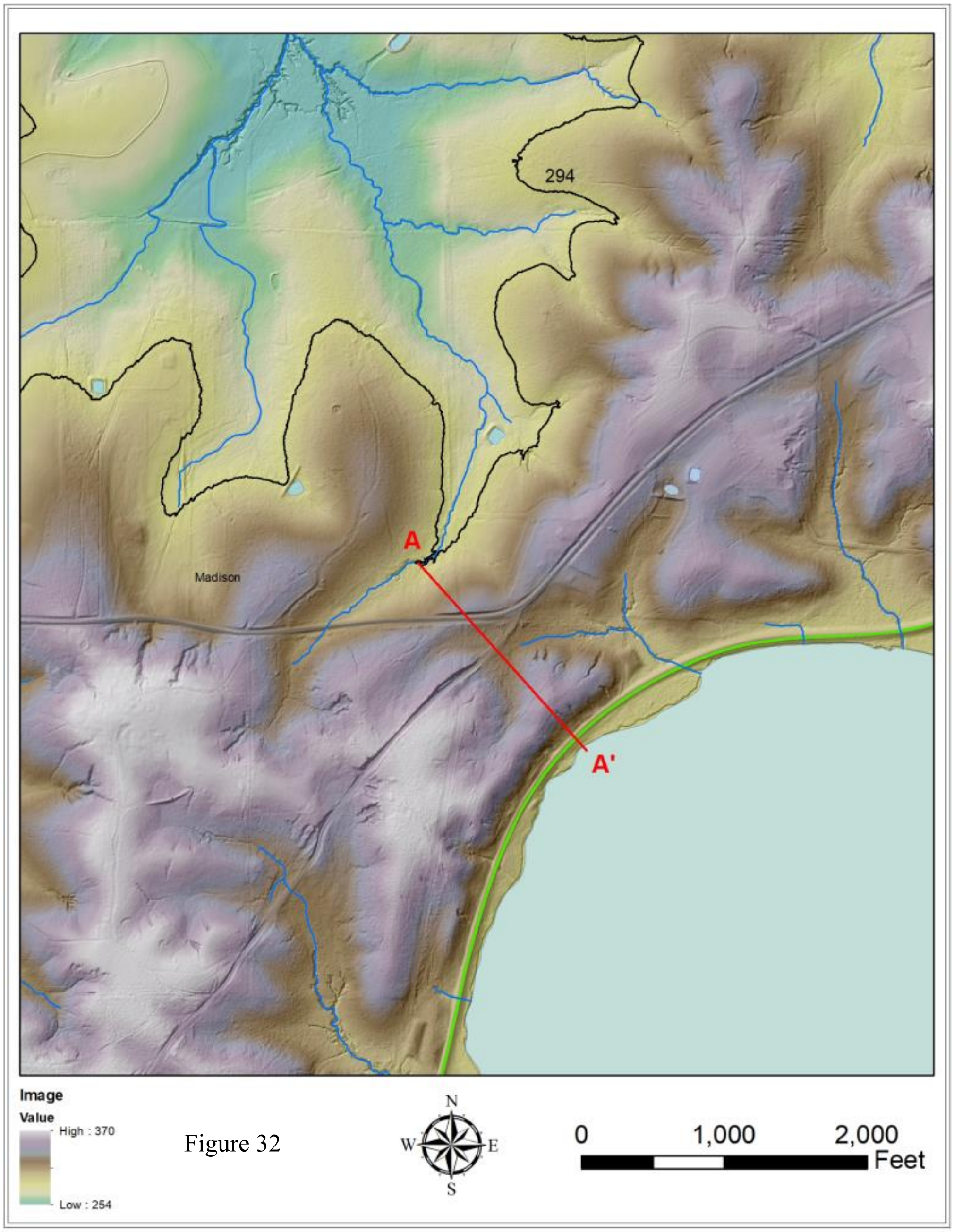


Figure 32

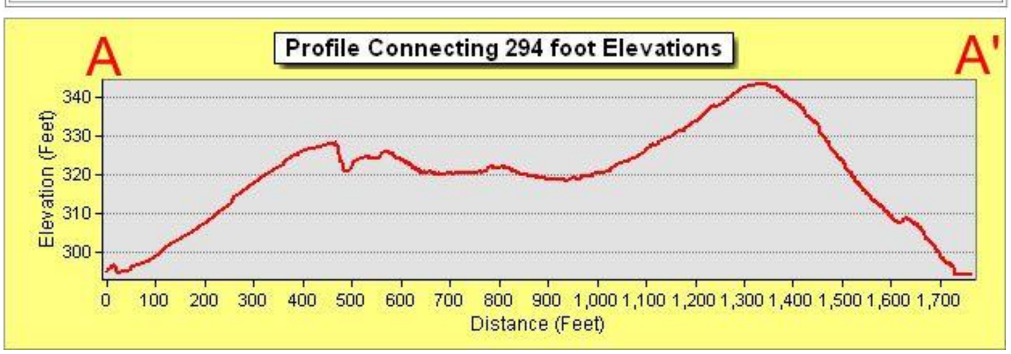


Figure 33

SOILS AND SURFICIAL GEOCHEMISTRY

Soils in Mississippi are weathered surficial deposits derived from: (1) "bedrock" strata, (2) the fine-grained surfaces of alluvial fills, which are the average of a river or stream basin's weathered bedrock composition, and (3) loess, the largely windblown dust transported from glacial rock flower deposited on the Mississippi River Alluvial Plain. Soils developed on Mississippi's Loess Belt were some of the richest soils in the state and promoted plantation farms along the Mississippi River from Natchez, Mississippi, to Memphis, Tennessee. As farm land became less productive along the eastern seaboard, many farm families migrated west to Mississippi. The writer's family was part of this migration, a great-great uncle buying three land patents of 160 acres each in 1838, two in Benton and one in Marshall County, before settling in the town of Hernando in DeSoto County, Mississippi. He was soon joined by other family members moving west from the tired Piedmont and Triassic Basin soils of Richmond County, North Carolina.

Eugene W. Hilgard, Ph. D., the fourth and sixth State Geologist of Mississippi and Director of the Mississippi Geological Survey from 1858-1866 and 1870-1872, published a statewide soil survey in his 1860 *Report of the Geology and Agriculture of Mississippi*. Hilgard's initial field work in Mississippi led him to the conclusion that a geologic survey could not "maintain itself in public esteem on the basis of mineral discoveries, and that it must seek its main support in what services it might render to agriculture" (Amundson and Yaalon, 1995). Hilgard noted a close connection between bedrock geology and surface vegetation and utilized floral assemblages in mapping formations and searching for outcrops. Howe (1964) published a brief history of Hilgard's work as a geologist.

During his work in Mississippi, Hilgard developed concepts with respect to soil surveying that he promoted for the next 30 years, including (1) the relation of soils and bedrock to vegetation types, (2) soil stratification (i.e. soil and subsoil), (3) the importance of soil chemical analysis, and (4) and the use of geologic maps and physiographic provinces in determining the distribution of soil types (Amundson and Yaalon, 1995). The later concept can be seen in Hilgard's (1884) "Agricultural Map of the State of Mississippi," which shows regions of physiography and vegetation types. Hilgard moved to Berkeley, California, in 1875, where he developed a College of Agriculture and set up soil experiment stations. Jenny (1961) acknowledged Hilgard's pivotal role in the "birth of modern soil science," while Pittman (1983) acknowledged that Hilgard was "renowned as 'the father of soil science.'" According to Bograd (1993), Hilgard was acknowledged both as "Father of Gulf Coast Geology" and as "Father of Soil Science." A memorial to him, detailing his career and publications, was written by the State Geologist of Alabama, Eugene A. Smith (1917).

Hilgard (1907, p. 487-510) published a textbook on soils entitled "Soils: Their Formation, Properties, Composition, and Relations to Climate and Plant Growth in the Humid and Arid Regions," which, in Chapter 24, included a section on his soil studies in Mississippi. In this chapter under the heading "Vegetative belts in northern Mississippi," Hilgard recognized the following north-south trending regions (sub-belts not included): (1) **Limestone Belt** above a narrow belt of Carboniferous limestones, (2) **Pine Hills** above non-calcareous Cretaceous beds, (3) **Prairie Belt** above Cretaceous chalk, (4) **Pontotoc Ridge** above sands of the Ripley Group and overlying formations, (5) **Flatwoods** above the Porters Creek clay, (6) **Brown Loam Table Lands** on loess cover and sandy Tertiary formations, (7) **Cane Hills** equivalent to the Loess Hills on the eastern bluff adjacent the Mississippi River Alluvial Plain, and (8) **Mississippi Bottom** on the Mississippi River Alluvial Plain. Hilgard also recognized a "Central Prairie" across the middle of the state, developed on calcareous Tertiary beds with oak and hickory growth, south of which was the "long-leaf-pine forest area of the state." In the "Pine Meadows" of coastal Mississippi, Hilgard noted the stunted growth of pines and cypress, two trees usually found in mutually exclusive habitats, sharing the same sour sandy soils of the coastal flats.

The U. S. Department of Agriculture established a Division of Agricultural Soil in 1884, which built on the work of Hilgard, especially in his work in the West on developing methods to identify soluble salts. The Division of Soil (new name) began work in earnest in 1899 on cooperative soil surveys with the various states. In Mississippi, this cooperative effort led to soil maps of Yazoo area in 1901, the Smedes area in 1902, and the Biloxi and Jackson areas in 1904. A cooperative effort with the Mississippi Geological Survey led to the 1908 publication of the Oktibbeha County soil survey. This effort produced 25 county soil publications from the 1908 Oktibbeha County survey to the Harrison County soil survey published in 1928. Later county soil surveys were published in a cooperative effort with the Mississippi Agricultural Experiment Station at Mississippi State University. County soil surveys published since 1955, which are still in print, are available from local Soil and Water Conservation District offices, Mississippi Agricultural Forestry Experiment Station, and the National Resources Conservation Service in Jackson, Mississippi. Of the 12 soil orders (broad soil groups) recognized in the United States, 8 occur in Mississippi (Pettry, 2006).

Caplenor et al. (1968) described the affect of loess cover on forest conditions in west-central Mississippi. They found the flora of the thick loess deposits in the Bluff Hills north of Vicksburg to be characterized by: (1) dominance of mesophytic hardwoods containing sweetgum, basswood, water oak, poplar (tuliptree), cherrybark oak, and bitternut, (2) importance of calciphiles, (3) importance of cane in upland sites (as opposed to its usual lowland occurrence), and (4) the presence of the umbrella tree *Magnolia acuminata*. Camp Kickapoo in northwestern Hinds County was selected as the site for the study of "vegetation in the area of thin loess." This area was dominated by mixed hardwoods, including beech, black gum, black oak, mockernut hickory, white oak, sourwood, and sweet gum. The shrub layer contained saplings of the above and witch hazel, wild black cherry, highbush, huckleberry, winged elm, and flowering dogwood. The disturbed hilltops and rolling lands were dominated by post oak, Spanish oak, and blackjack oak. Caplenor et al. (1968) found the principal environmental factor delimiting flora communities to be the availability of water. Thick loess was found to have a higher percentage of moisture than did the thin loess and thus had a flora most like that of non-loess bottom lands.

Other rich Mississippi soils developed on the Black Prairie above weathered Cretaceous chalks of the Selma Group and on the Jackson Prairie above weathered Late Eocene clay of the Yazoo Formation. Prairie openings are anomalous in Mississippi due to the state's humid climate, which promotes dense forest growth. However, Hilgard (1860, p. 254-272, 330-347) noted the presence of open prairies in the "North-Eastern Prairie Region" (Black Prairie) and the "Central Prairie Region" (Jackson Prairie). Moran (1997) cited early writings about Black Prairie and Jackson Prairie and classified the soils of four native prairie remnants of the Jackson Prairie as "fine and very fine, smectitic, thermic Chromic Hapluderts on level to gently sloping upland positions." This classification is "indicative of the high shrink-swell potentials and high color values inherited from the Yazoo Clay."

Pettry and Switzer (1993) noted that shrinking and swelling in the Yazoo Clay produced an uneven, hummocky micro-relief, which Hilgard (1860) referred to in Smith County, Mississippi, as "hogback" or "hogwallow" (**Figure 15**). This micro-relief is presently referred to as Gilgai, an Australian Aborigine word for seasonal water accumulations in the "hogwallows." Pettry and Switzer (1993) listed the acreage of expansive soils in the "Blackland Prairie," "Interior Flatwoods," "Delta," "Coastal Plain," and "Loess" of Mississippi and found these soils to cover 18% of the state, with the largest acreage in the Blackland Prairie and Delta.

Thompson et al. (1998) discussed the methodology and sample coverage for a surface geochemistry survey of Mississippi. Thompson et al. (2002) gave the survey results for the minimum, median, and maximum values of arsenic, selenium, mercury, copper, lead, and zinc found statewide. They noted the Delta and Gulf Coast to have significantly higher baseline values of these toxic metals when compared to adjacent terrains (**Figure 34**). Leslie (2004) gave an update and web address for the National Geochemical Survey by the U. S. Geological Survey, which showed the survey completed in Mississippi as depicted in a national map of arsenic values.

Pettry and Switzer (2001) reported on arsenic concentrations in selected Mississippi soils and listed arsenic concentrations according to the parent bedrock materials from which the soils developed. They noted a correlation between high iron and arsenic contents and found the highest arsenic values in the Winona Formation and Mississippi River alluvium of the Delta region.

Pettry et al. (1988) reported landslides (soil mass movements) in particular soils developed on the "Ackerman Formation" (=Nanafalia Formation) of the Wilcox Group in southeastern Choctaw and northwestern Winston counties. These landslides occurred on slopes of 12% to 50% and on soils mapped as the Maben-Providence association in the Choctaw County soil survey report (U. S. Department of Agriculture Soil Conservation Service, 1986).

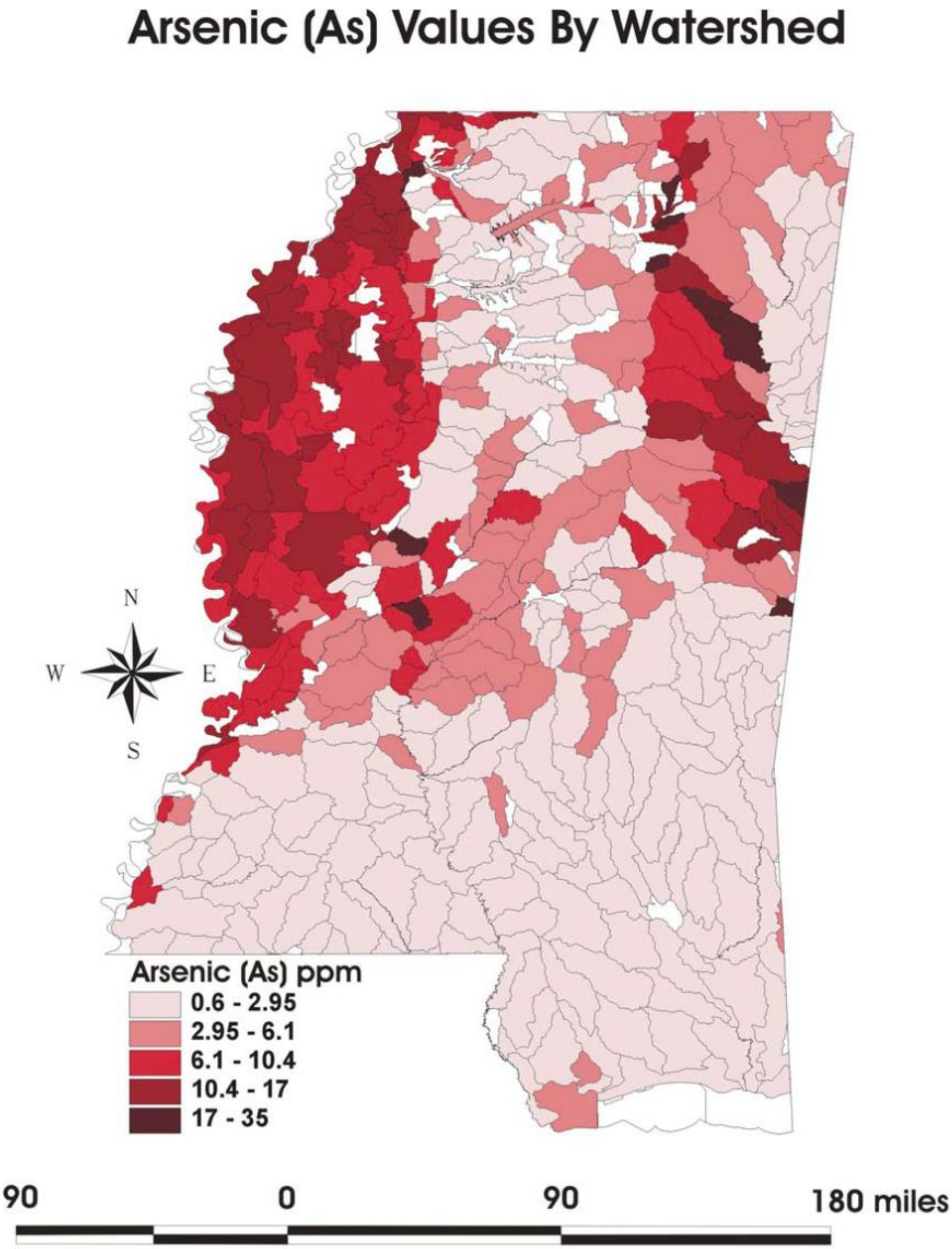


Figure 34. Arsenic values by watershed as determined from the Solid-phase geochemical survey of the State of Mississippi by David Thompson and others (2002); an atlas highlighting the distribution of As, Cu, Hg, Pb, Se, and Zn in stream sediments and soils. High arsenic values occur in the agricultural lands of the Delta region, the Black Prairie, and the western Jackson Prairie.

CHAPTER 2. GROUND WATER

Statistics of the Mississippi Office of Land and Water Resources (OLWR) indicate there are about 80,000 water wells in the U.S. Geological Survey (USGS) files in addition to 45,000 wells in the records of OLWR, which were not tracked by the USGS, for a total of 125,000 Mississippi water wells on file, a number far short of the actual number of water well drilled in Mississippi. Of these wells, some 18,300 are permitted by OLWR, 11,500 (or most) of which are irrigation wells in the Delta. More water is pumped from the Mississippi River Valley alluvial aquifer for agricultural purposes than is pumped from all other aquifers (and for all other usages) combined. According to Arthur (2001, p. 36), the average annual pumpage rate from the alluvial aquifer used in the USGS calibrated model for a period between 1988 and 1996 was about 1.27 billion gallons per day. This is a huge volume of water when compared to public and industrial water withdrawal from all aquifers in northeastern Mississippi, which Strom (1998, p. 27) calculated at 76 million gallons a day for the year 1995. According to the Mississippi Water Resources Management Planning Council (1995, p. 7), irrigation and aquaculture (catfish ponds) account for 80% of ground-water pumpage in the state.

Bailey (2004) stated the importance of ground water to Mississippi with the following statistics:

1. Ground water accounts for more than 80% of the state's water supply, and is used for drinking water, manufacturing, irrigation, and electric power generation.

2. More than 93% of the state's drinking water comes from ground-water supplies.

3. Only 3 of the 1,535 public water systems in Mississippi utilize surface water.

4. Over 100,000 acres of farm-raised channel catfish ponds in Mississippi use ground water exclusively.

5. Many farmers are dependent on ground-water supplies for irrigation of crops such as rice and for the watering of livestock.

The Mississippi Office of Geology purchased its first wire-line logging unit in 1953 (Harrelson et al., 1980). Since that time the office has provided free logging service to water-well drillers, has logged its own test holes, has maintained a file of water-well geophysical logs, and has given lots of advice on ground-water availability.

The Best Available Drinking Water. Ground water is naturally filtered and, with the exception of shallow unconfined aquifers connected to the surface, is generally free of dangerous bacteria, parasites, and surface pollutants, which must be treated and eliminated in surface-water treatment plants. It seems at odds with the public interest that there are those who promote building reservoirs as a source of public-water in areas where there is an ample supply of ground water. As noted below, only 11% of the ground water pumped in Mississippi is used for public water supplies; the rest goes largely to irrigation and catfish ponds. The City of Columbus drilled its first municipal water wells in the Tuscaloosa Massive Sand Member in 1977 to begin its conversion from surface water to ground water for its public water supply. Its old water-treatment plant (illustrated in Lang and Boswell, 1960, p. 39) took its water supply from Luxapalila Creek.

Surface water can be deadly when not properly treated for public water supplies. The protozoan parasite *Cryptosporidium* lives in surface waters and is highly resistant to chlorine and other disinfectants and is so small that it is not easily removed from water by the type of filters used in conventional surface-water treatment plants. It is found in over half of the public water supplies tested that use surface water. An outbreak of *Cryptosporidium* in the Milwaukee, Wisconsin, public water supply in 1993 killed 100 people, made another 400 sick, and affected 400,000 people. In New Orleans on May 3, 1999, Ed Fidler, a well-known ex-sportscaster for WLBT-Channel 3 in Jackson, Mississippi, died from *Cryptosporidium* at the young age of thirty nine (Pettus, 1999). There are treatments for those infected by *Cyptosporidium*, but no cure.

The City of Jackson has the largest surface-water-treatment system in the state. This system was cited by the U.S. Environmental Protection Agency in 2000, twice in 2001, 2002, 2003, and 2004 for violating clean -water standards or for failure to report. Most of the citations were for unacceptable levels of trihalomethane (TTHMS), a byproduct produced when chlorination kills microbes that comprise part of the total organic content (TOC) of the surface water supply. The City of Jackson published a "Notice to Customers" dated May 11, 2005, stating that "City of Jackson Surface Water System has levels of Trihal-

Figure 35. How to find an abandoned cistern in late winter time? Look for the flowers around the old home site. The cistern and flowers are now in a large field on the Jackson Prairie along Kickapoo Road in northwestern Hinds County, where the Yazoo Clay was too thick to permit hand dug wells. Picture (color negative 569-2: Image 341) taken on March 5, 2006.

omethane (TTHM) and Haloacetic Acids (HAA5) above Drinking Water Standards" (*Clarion-Ledger,* 2005). Under the heading "What does this mean?," the city stated that there was not an immediate risk, but that "some people who drink water containing trihalomethanes in excess of the MCL [maximum contaminant level] over many years may experience problems with their liver, kidneys, or central nervous system, and may have an increased risk of getting cancer." It should be noted that groundwater colored by organic compounds will also produce TTHM when chlorinated.

An algal bloom in the Ross Barnett Reservoir, the source of Jackson's drinking water, in May and June of 2007 turned the city's water supply into discolored, foul-smelling, bad-tasting drinking water. Restaurants were force to switch from tap water to bottled water. A section on the front page of the May 30, 2007, edition of the *Clarion-Ledger* read "City flushing pipes to clear out foul water." The article stated that "Chemicals (i.e. chloramines and potassium permanganate) used seasonally to treat algae at the O.B. Curtis Water Treatment Plant in Jackson have produced an aftertaste, odor and color in city water that has lingered for more than two weeks" (DeRoy, 2007). Later, in the Metro/State section of the paper, a headline reported: "Water 'safe' but problems linger." The article noted the following: "The reason Jackson, but not surrounding areas, experienced unpleasant water is that most of Jackson's supply is surface water" (Baydala, 2007).

Now it is reported (Associated Press, 2008) that public water supplies, which utilize surface water, are tainted with an array of pharmaceuticals. Drinking-water supplies for some 41 million Americans were found to contain traces of such drugs as antibiotics, anti-convulsants, mood stabilizers, and sex hormones. A total of 56 pharmaceuticals or byproducts were found in the drinking water of Philadelphia, Pennsylvania, including medicines for pain, infection, cholesterol, asthma, epilepsy, mental illness, and heart problems. Though these drugs are measured in concentrations of parts per billion or trillion, scientists are concerned about the long-term consequences they present to human health.

James C. McDonald was a professional engineer who worked for the Mississippi State Department of Health for 36 years (1956-1992) as head of the Bureau of Public Water Supply. He was an ardent believer that only groundwater should be used for human consumption. Under his tenure he made it tough for anyone to get a Board of Health permit to supply people with surface water. There had to be virtually no other alternative.

Ground-Water Chemical Monitoring. The Mississippi Agricultural Chemical Groundwater Monitoring Program of the Mississippi Office of Land and Water Resources has sampled water in a total of 1,369 wells over a period from March 1, 1989, to December 31, 2007. Of this total, 664 drinking-water wells from all 82 counties were analyzed for more than 100 pesticides and metabolites, 45 volatile organic compounds, and 30 inorganic compounds, including minerals, residues, nutrients, and metal. The other 705 wells were for irrigation and fish culture in all 19 Delta counties and were analyzed only for pesticides, chlorides, and nitrates.

Test result of the 1,369 wells samples found no detectable concentrations of agricultural chemicals in 1,324, or 96.7%, of the wells. Only three wells were found to contain concentrations exceeding safe levels (Maximum Contaminant Levels or MCLs). Of the three wells, two were found to be contaminated from improper storage of chemicals near the wellhead. After clean-up of the area around the wells, subsequent sampling showed no pesticide contamination.

Analysis for total nitrates, chemicals closely associated with agricultural practices, found only nine of 1,369 wells samples to exceed the MCL for total nitrates. Resampling has indicated that five of the nine wells are presently within allowable limits (Mississippi Agricultural Chemical Groundwater Monitoring Program, Summary and Results, March 1, 1989 Through December 31, 2007).

Ground Water and Early Settlement. Fresh water is Mississippi's most valuable natural resource. Reliable springs and shallow aquifers were important to early settlers and the locations of early towns. In fact, groundwater resources were a matter of great concern even in Biblical times. The 26th chapter of Genesis tells that Isaac moved to the valley of Gerar to re-dig the wells of his father Abraham, which the Philistines had filled in with dirt. The first well was such a success with flowing water that the herdsmen of Gerar claimed, "The water is ours." Then Isaac dug another well, only to have the herdsmen claim it, too. Finally, Isaac moved to another site and dug a well that no one quarreled over, and so he named it Rehoboth, meaning "At last the Lord has made room for us, and we shall be fruitful in the land."

Potable water was also important to the establishment of Mississippi's early settlers such as Silas Dinsmoor, who was the Choctaw Agent for Mississippi between 1802 and 1816. In 1811, Dinsmoor built an Agency house at Ridgeland, Mississippi, near the intersection of Old Agency Road and the Natchez Trace right-of-way. This house measured 72 by 30 feet and was scandalously large for an Agency house of its time. To provide for the large water supply needed by the Agency's many guests, Dinsmoor dug a well in late 1811 and early 1812 (Elliot, 1998) to a depth of 172 feet in stiff Yazoo Clay before abandoning the project as a dry hole.

Even if Dinsmoor had dug his well twice as deep, it would still have been dry, because the Yazoo Clay is as much as 400 feet thick in the Ridgeland area. The Agency later dug an additional cistern to supplement their water supply. Today cisterns of old home sites dot the landscape of the Jackson Prairie across central Mississippi where the Yazoo Clay is thick (**Figure 35**). Similar cisterns dot the landscape of the Black Prairie and Flatwoods in northeastern Mississippi on the Cretaceous chalk and Porters Creek clay belts. Crider (1906, p. 24) reported that he knew of no wells that penetrated the Porters Creek clay and estimated the thickness as 210 feet.

Figure 36. How to find an abandoned cistern on a cold fall morning? Look for a puff of vapor rising from an old homesite. This is the same cistern as in the previous figure. It is in a field on the south side of Kickapoo Road on the Yazoo Clay outcrop belt in northwest Hinds County. Picture (digital; Image 1107) was taken on the morning after the first fall frost on October 28, 2008.

Cisterns have been used since ancient times in areas where ground-water resources were very deep or absent. They generally have a narrow neck at the surface and expand below to a large cylinder or basin to catch the rainwater funneled from the roof of a house. A cistern on the north side of Kickapoo Road near the intersection of Tinnin Road in northwestern Hinds County is typical of many cisterns on the Yazoo Clay outcrop belt. It has a modest brick, well-like upper structure and concrete covering at the surface, which hides a huge cavity below--a deep and expanded cylindrical cavity that looks like a missile silo. This structure was built large enough to store rainwater from wet months to be used in the dry months or, even worse, in dry years. Before drinking the water, it was best to sieve out the "wiggly worms" through a cloth. Even so, the coliform bacterial count from bird droppings and other sources would not pass our Health Department standards of today. On cold winter mornings, abandoned cisterns can be spotted along Kickapoo Road along the sides of rolling fields or by cedar groves by the ascension of their wispy vapors, the only records of long forgotten homesteads (**Figure 36**).

Base of Fresh Water. Modern drilling technology provided the means to penetrate thick clay and chalk units to reach the underlying aquifers. By 1854, Wailes (1854, p. 268) reported 18 flowing artesian wells in Lowndes and Noxubee counties and estimated as many as 100 such wells in the state. Hilgard (1860, p. 79, 272) reported wells drilled deeper than 1,000 feet in southern Chickasaw and Clay counties. In 1963, a few wells drilled before 1860 were reported to have been in continuous use for over 100 years (Boswell, 1963, p. 17). Stephenson et al. (1928) published "The Ground-Water Resources of Mississippi," which included a statewide map (pl. 8), showing the locations of artesian wells with surface flows. Such wells occurred in river flood plains, the Mississippi River Alluvial Plain, and the coastal area.

Though towns and other developments are no longer restricted to sites with a shallow water table accessible to hand-dug wells, there are other limits to how deep water wells can be drilled. Water salinity generally increases with depth, and the base of fresh water (which for purposes here is considered to be water containing less than 1,000 parts per million of dissolved solids) varies between a few hundred feet deep in northeastern Tishomingo County to greater than 3,000 feet deep in various places such as parts of Grenada and Yalobusha counties, Smith and Jasper counties, and Pearl River County (Newcomb, 1965). Priddy (1955) published a map of Mississippi showing the recharge areas of aquifers and the down-dip limit of their fresh water.

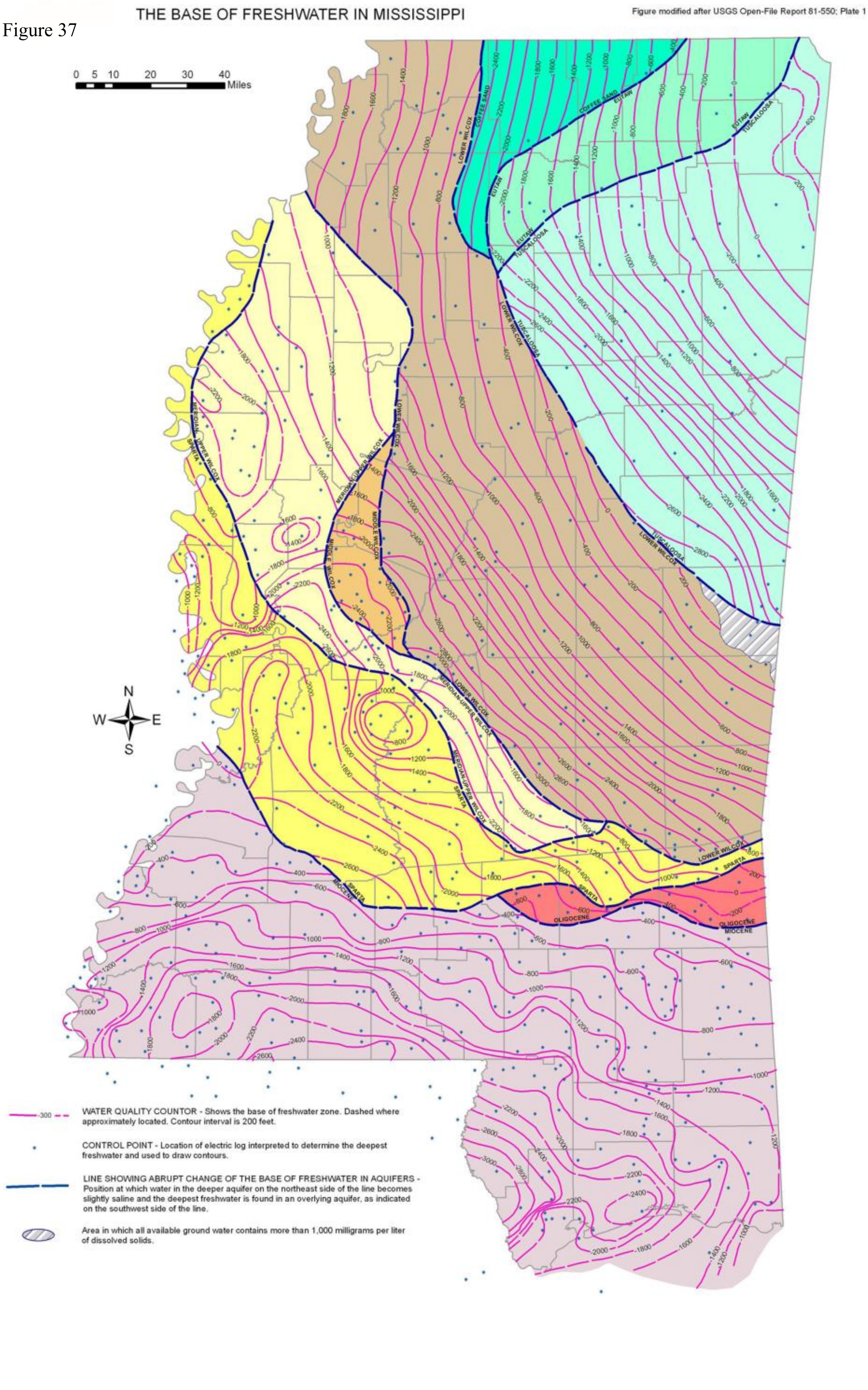
Shows (1970, fig. 2) gave a map showing the "configuration of the base of freshwater in Mississippi," which partitioned the state into aquifer regions including: (1) Tuscaloosa, (2) Lower Cretaceous, (3) Eutaw, (4) Coffee Sand, (5) Wilcox, (6) Meridian Sand, (7) Claiborne, and (8) Miocene aquifers. An area in southeastern Kemper County and northwestern Lauderdale County was shown to have "no fresh water available." Another map (Shows, 1970, p. 20, fig. 3) gave the "distribution of major ground-water aquifers." This map included six regions as follows: (1) Cretaceous and Paleozoic aquifers, (2) Cretaceous aquifers, (3) Claiborne and Wilcox aquifers with a subregion in the north labeled Ripley and Coffee Sand aquifer, (4) Alluvium, Claiborne, and Wilcox aquifers, (5) Citronelle, Hattiesburg, Catahoula, Claiborne, and Wilcox aquifers, and (6) Citronelle, Graham Ferry, Hattiesburg, and Catahoula aquifers. Gandl (1982) published a 1:500,000 scale map entitled "The base of fresh water in Mississippi." **Figure 37** is a revision of Gandl's map by D. Thomson.

The depth to the base of fresh water poses a problem along a west-northwest to south-southeast zone of central Mississippi just south of the Yazoo Clay outcrop belt. Here, surficial Miocene aquifers are too shallow to supply commercial quantities of water, and the Eocene Sparta aquifer is deep and near to the base of the fresh water interval. Also, there is the problem of colored water in the deeper aquifers. South of the Yazoo Clay outcrop belt in Wayne County the base of fresh water is less than 1,000 feet deep. Here, the City of Waynesboro once relied on a shallow lenticular Oligocene aquifer, known as the Waynesboro Sand, for its ground water (Johnson, 1982). To solve its need for more water, the city drilled a well north of town into the lower Wilcox Group, where the aquifer was at a shallower depth and of a better water quality, and built a pipeline to carry the water to town. A water well for the Town of Hiwannee, north of Waynesboro, gets its water from the lower Wilcox aquifer with the base of the screen at a depth of 2,777 feet, making it one of the deepest wells for drinking water in the state.

Terry, Mississippi, is also situated south of the Yazoo Clay outcrop belt and faces a similar problem to that of Waynesboro. The town water supply comes from wells that tap a north-south channel sand in the lower Forest Hill Formation (Oligocene), which extends through sections 9 and 16 of T. 3 N., R. 1 W. north of, and in, west Terry. These wells have the greatest discharge rates of any Forest Hill wells in the state. The South Central Water Association's well (V095) in Section 9, with a 50-foot-long screen in the Forest Hill channel sand, has a discharge rate of 927 gallons per minute (Oakley and Burt, 1992, p. 40). Three other public-supply wells in the same channel sand have discharge rates of 500 gallons per minute. Away from the channel, discharge rates drop to 350 gallons per minute or much less.

For additional water in the Terry area, the South Hinds County Water Association recently drilled a 2,000-foot-deep well to tap the Sparta aquifer (newspaper article by Berry, 2000). Lowe (1919, p. 117) attributed a 56-foot-deep well in an outlier of the Forest Hill aquifer at Pocahontas, Mississippi, to the "Jackson sands." This shallow aquifer was adequate for only modest water-supply needs. Beyond that, a deeper well would have to penetrate more that 400 feet of Yazoo Clay and the upper clayey beds of the Cockfield Formation before reaching the first Cockfield aquifer sand. A more recent private well at Pocahontas has a screened interval from 500-540 feet in the upper Cockfield; a roadside park well just south of Pocahontas is screened in the lower Cockfield at 756-776 feet.

Figure 37


THE BASE OF FRESHWATER IN MISSISSIPPI
Figure modified after USGS Open-File Report 81-550; Plate 1
0 5 10 20 30 40 Miles
N
W
E
S
WATER QUALITY COUNTOR - Shows the base of freshwater zone. Dashed where approximately located. Contour interval is 200 feet.
CONTROL POINT - Location of electric log interpreted to determine the deepest freshwater and used to draw contours.
LINE SHOWING ABRUPT CHANGE OF THE BASE OF FRESHWATER IN AQUIFERS - Position at which water in the deeper aquifer on the northeast side of the line becomes slightly saline and the deepest freshwater is found in an overlying aquifer, as indicated on the southwest side of the line.
Area in which all available ground water contains more than 1,000 milligrams per liter of dissolved solids.

Aquifer Value. In 1955 (according to Priddy, 1955, p. 19), the ranking of aquifers in order of importance was as follows: (1) Miocene (lumping the Catahoula, Hattiesburg, Pascagoula, and Graham Ferry aquifers), (2) Wilcox (lumping the lower, middle, and upper Wilcox aquifers), (3) Sparta, (4) Cockfield, (5) Tuscaloosa, (6) Winona, (7) Eutaw, (8) Pennsylvanian, (9) Mississippian, (10) Vicksburg, (11) Forest Hill, and (12) Devonian. This ranking was made shortly after the drought of 1950-1954 and before the Mississippi River Alluvial aquifer was developed for irrigation. Today the ranking of top aquifers (Hoffmann, personal communication) would be: (1) Mississippi River Valley Alluvium, (2) Miocene, (3) Wilcox, (4) Sparta, (5) Lower Cretaceous and Tuscaloosa, (6) Cockfield, and (7) Eutaw-McShan, (8-10, listed alphabetically, are of about equal value: 8) Coffee Sand, (9) Paleozoic (lumping the Devonian, Mississippian, and Pennsylvanian), (10) Ripley, (11) Citronelle-High Terraces, (12) Oligocene, and (13) Winona-Tallahatta. Lang and Boswell (1960, p. 32) gave the distribution of aquifer use in northern Mississippi, listing the following regions from east to west and north to south: (1) Tuscaloosa Group, (2) Eutaw Formation and Coffee Sand, (3) Tuscaloosa Group and Eutaw Formation, (4) Eutaw and Ripley formations, (5) Wilcox and Claiborne groups, (6) Wilcox Group, and (7) Claiborne Group.

Memphis, Tennessee, and Northwestern Mississippi. Ancient Tertiary delta systems, such as that of the Sparta and Cockfield aquifers, tend to be sandier updip (to the north) where fluvial facies dominate. This is also the case for the Hatchetigbee Formation of the upper Wilcox Group, which merges with sands of the Meridian Formation of the Claiborne Group in central Mississippi to form the Meridian-upper Wilcox aquifer. Northward near the Tennessee line, the Meridian-upper Wilcox aquifer merges with sands of the overlying Tallahatta, Winona, Zilpha, and Sparta formations (Arthur and Taylor, 1998, p. I10, table 1) to form a single thick aquifer unit named the Memphis Sand.

The May 19, 2008, edition of The Commercial Appeal contained a section on news from 25, 50, 75, 100, and 125 years ago. The heading "100 years ago: 1908" gave the following report: "The largest artesian well ever discovered in Memphis was tapped by the Water Department yesterday at its auxiliary plant at Central and Tanglewood. The well shows a flow of almost 4,000,000 gallons a day from a depth of only 460 feet." This well produced water from the Memphis Sand aquifer.

Brown (1947) reported that the first artesian well in the Mississippi River Alluvial Plain was drilled at Greenwood in Leflore County by C. E. Wright in 1896, just ten years after the discovery of flowing water at Memphis, Tennessee. He also reported that some 50 deep flowing wells were drilled in the delta counties between 1896 and 1904. Some of these wells were drilled into the Sparta aquifer (which is equivalent to the upper part of the Memphis Sand aquifer), while others were drilled into the Meridian-upper Wilcox aquifer (Hoffmann and Grantham, 2000a) and the lower Wilcox aquifer (Hoffmann and Grantham (2000b). Brown (1947) also reported that some 1,300 flowing wells had been drilled in Mississippi Delta counties between 1896 and the publication of his book in 1947.

The City of Memphis uses the Memphis Sand aquifer and, to a lesser degree, the Fort Pillow Sand aquifer below, as its sole water supply, and boasts the best drinking water of any large metropolitan city. According to a brochure by the Memphis Light, Gas and Water Division (undated), the Memphis well field contains 170 wells, each capable of producing three million gallons of water per day. In all, a total of about 196 million gallons of water per day is pumped from the Memphis aquifer in southwestern Tennessee, of which approximately 60% (about 118 million gallons per day) is used by the City of Memphis. A regional ground-water model by the U. S. Geological Survey (USGS) indicates that this pumpage has increased the ground-water flow from Mississippi into the Memphis well fields (Mississippi Water Resources Management Planning Council, 1995, p. 18). Such information was reported on the front page of *The Commercial Appeal* under the caption "Memphis taps into DeSoto County's well levels" (Charlier, 1998).

Dolbi (2005b) of the *DeSoto Times* reported that on peak days Memphis Light, Gas & Water and surrounding municipalities pump nearly 210 million gallons of water to more than 1 million residents. This water also supplies some "84 companies that provide 2,500 jobs with a $1 billion economic impact directly affected by the aquifer."

Water Wars? Water wars are generally fought between states over rights to surface water from streams and rivers. Perhaps the first recorded "legal settlement" over ground-water rights was recorded in the book of Genesis (chapter 21, verses 22-34) where Abraham took possession of a disputed water well at Beersheba (in the land of the Philistines), a name signifying that Abraham and King

Abimelech took an oath and made a covenant concerning the well. In DeSoto County, Mississippi, and Shelby County, Tennessee, water-right problems exist where the City of Memphis and DeSoto County share the same aquifer system, the Memphis Sand Aquifer. Feldman and Elmendorf (2000, Chapter 5.4, p. 54-59) addressed the "Tennessee-Mississippi liability problems" concerning the Memphis Sand Aquifer in sections 5.5.1-5.5.3 of a report to the Environmental Policy Office of the Tennessee Department of Environment and Conservation.

In a rather unique lawsuit filed on February 2, 2005, the State of Mississippi sued Memphis for tapping Mississippi ground-water supplies in the Memphis water-well fields. An Associated Press (2005) article published in the March 6, 2005, issue of the Clarion Ledger stated that Memphis Light, Gas, and Water Division (MLGW) withdraws 160 to 200 million gallons a day from the Memphis Sand aquifer, a withdrawal volume significant enough to suck water from ground-water supplies in northwestern Mississippi. The May 1, 2005, edition of the *Commercial Appeal* cited "Mississippi officials" as labeling Memphis as the largest single user of Mississippi ground water but noted added pressure on the aquifer from Olive Branch, Mississippi, which increased its pumping rate from 1.23 million gallons a day in 1995 to nearly 3.5 million in 2000 and from Southaven's daily consumption, which rose from 1.9 million gallons in 1994 to 3.3 million gallons in 2003 (Charlier, 2005). The May 5, 2005, edition of the DeSoto Times reported that DeSoto County had joined the suit alleging that Memphis pumps 300 million gallons per day of which 60 million is drained from the portion of the aquifer beneath DeSoto County (Dolbi, 2005a).

In 2008, U.S. District Judge Glen Davidson ruled that the state of Tennessee, though not named in the suit, had to be a party to it, making the case an interstate dispute under the Supreme Court's jurisdiction. The Fifth Circuit Court of Appeals upheld that ruling in June of 2009. On February 1, 2010, the Supreme Court declined to hear a lawsuit claiming that Memphis was pumping too much water out of a shared aquifer, thus denying Mississippi's claims against Memphis.

Northeastern Mississippi. In Tishomingo County of Northeastern Mississippi, the sands and gravels of the Tuscaloosa Group (Gordo Formation) are a source of ground water. However, this aquifer thickens in Cretaceous valleys cut into the Paleozoic bedrock and thins over Paleozoic highs (**figures 38-41**). The Town of Corinth in neighboring Alcorn County overlies a Paleozoic high and once obtained ground water from fractured Devonian chert (Jennings, 1994). Lee et al. (2003) reported on the geochemistry of ground waters in the Devonian and Lower Mississippian aquifers of northeastern Mississippi and found them to have the chemistry of waters derived from weathered crystalline rocks, which once bordered the Mississippi Embayment.

In Cretaceous outcrops of northeastern Mississippi, geology and well-water/spring-water availability are responsible for an interesting pattern of settlement. Here the Black Prairie is a region of excellent farm lands but few towns due perhaps to the lack of a shallow aquifer for ground water. Beginning at Tupelo and continuing north into Tennessee is a north-south geologic boundary marking the edge of the Black Prairie and the top of an aquifer known as the Coffee Sand. Also beginning at Tupelo, and continuing northward along the contact of the Demopolis Chalk, which forms the Black Prairie, and the Coffee Sand are the towns of Tupelo, Saltillo, Guntown, Baldwin, Frankstown, Booneville, Rienzi, and Corinth. All these towns and U.S Highway 45, which connects them, are situated between farm land to the west and an aquifer to the east. As these towns have grown, they have tapped even deeper Cretacous aquifers, including the Eutaw -McShan aquifer (Everett and Jennings, 1994; Strom and Mallory, 1995) and the Gordo aquifer of the Tuscaloosa Group (Phillips and Hoffmann, 1994). At Corinth, where the city sits on a Paleozoic structural high and the Tuscaloosa is absent, wells pump more than a million gallons of water a day from fractured Paleozoic basement rocks (Jennings, 1994).

The Demopolis-Coffee Sand contact is exposed at several places along U.S. Highway 45 between Tupelo and Corinth. One notable site is at Frankstown where highway excavations in 1990 for the Frankstown bypass encountered so many fossil shark teeth at the Demopolis-Coffee Sand contact that fossil collectors from distant states came to collect them. These fossils generated such publicity that Booneville High School was awarded a National Science Foundation grant (the first ever awarded to a high school) to use the site as a project in teaching their students earth science. The site and Booneville High School made national news on an ABC Sunday evening newscast. Fossils from this site are illustrated in Circular 4 of the Office of Geology (Manning and Dockery, 1992). Today, the geologic boundary that spawned a corridor of towns is remembered, not for its ground water, but for its fossils, as attested by an eight-foot-high

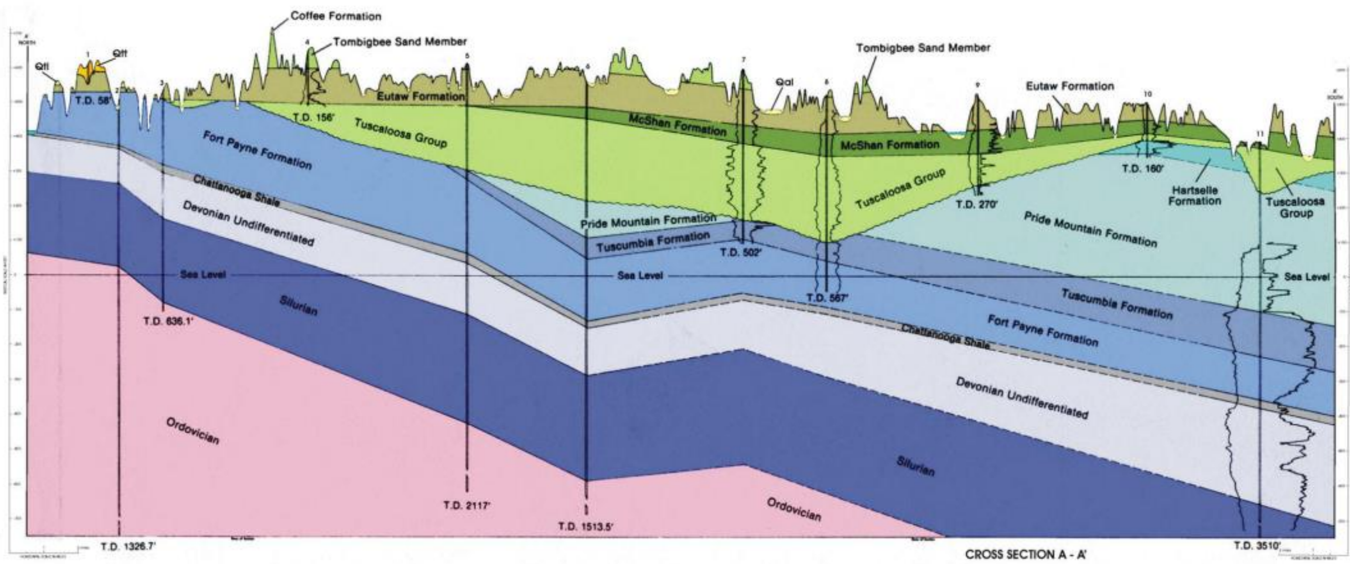


Figure 38. North-south cross section (south at right) through Tishomingo County, showing the incision of Tuscaloosa gravels into the Paleozoic basement and Paleozoic highs to the north, where the Tuscaloosa is absent. Tuscaloosa channels are an important ground-water resource. Cross section from Merrill (1988, pl. 2).

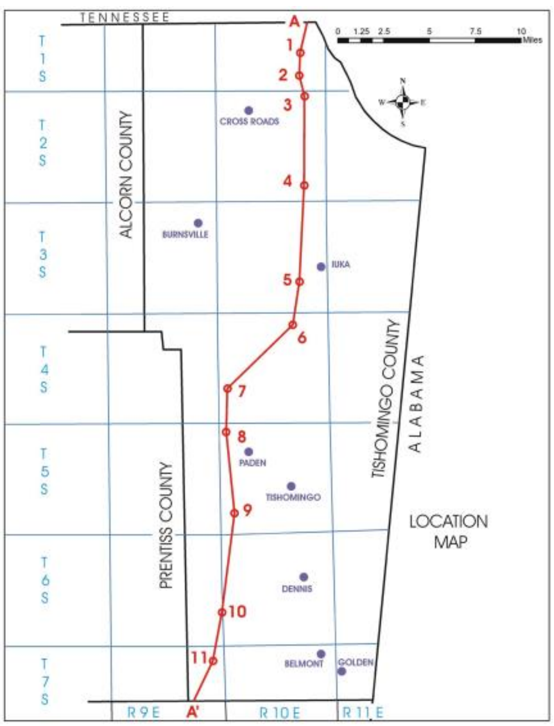
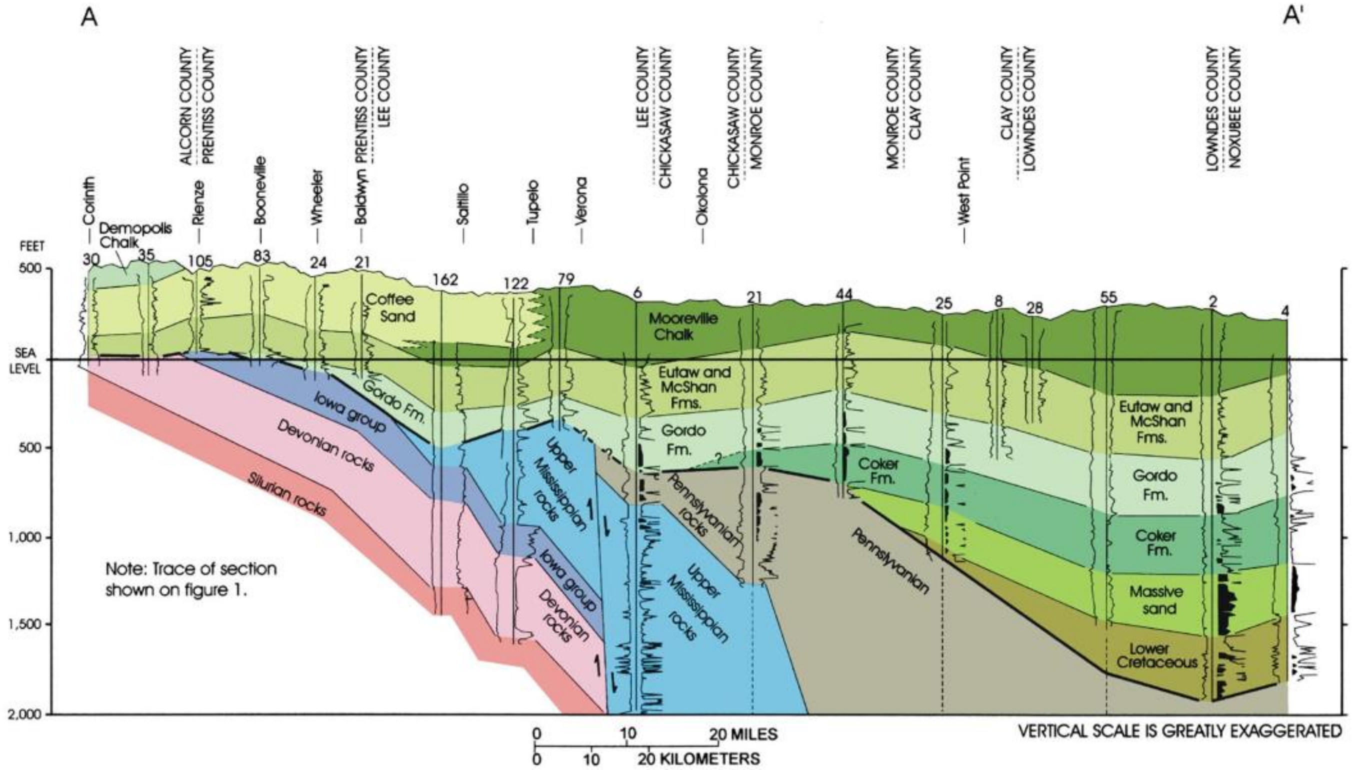


Figure 39. Tishomingo County cross section location map.

granite monument at a roadside park just off U.S Highway 45 at Frankstown.

Another geologic boundary and associated water supply, which is perhaps responsible for a string of towns, is the famous Cretaceous-Tertiary Boundary, also known as the K-T Boundary. Here in the Tertiary strata, some 400 feet of Porters Creek Clay are separated from thick deposits of Cretaceous chalk below by a sand at the base of the Clayton Formation. The thickness of the basal Clayton sand is quite variable. The origin of this sand has been attributed to such novel processes as deposition in the tidal wave that followed the asteroid impact that killed off the dinosaurs (that impact crater is believed to exist under the Yucatan Peninsula). Whatever its mode of deposition, the Clayton sand is a source for shallow ground water and feeds springs along a narrow strip that connects Starkville, Houston, Pontotoc, New Albany, Ripley, and Walnut (Harris, 1896, p. 22, illustrated water flowing from a horizontal pipe below a ledge of *Turritella* limestone in the Clayton at Chalybeate Springs two or three miles east of Walnut). It is interesting to note that the name for Oktibbeha County, which contains Starkville, derives its name from an Indian word which means "pure water," while Noxubee County to the southeast comes from a word meaning "stinking water" (Schmitz et al., 1999).

Central Mississippi. In Hinds County in west-central Mississippi, many residential wells (such as the well at my sister-in-law's house) acquire their water from the Cockfield aquifer, the basal sands of which are 800 feet deep in the northwestern part of the county but supply clear water with a pH of 8.29 (8.3 to 8.5) is ideal, meaning no CO_2 and no corrosion, low iron and manganese, and no coliform bacteria. However, water color differs in the Cockfield Formation to the south and east



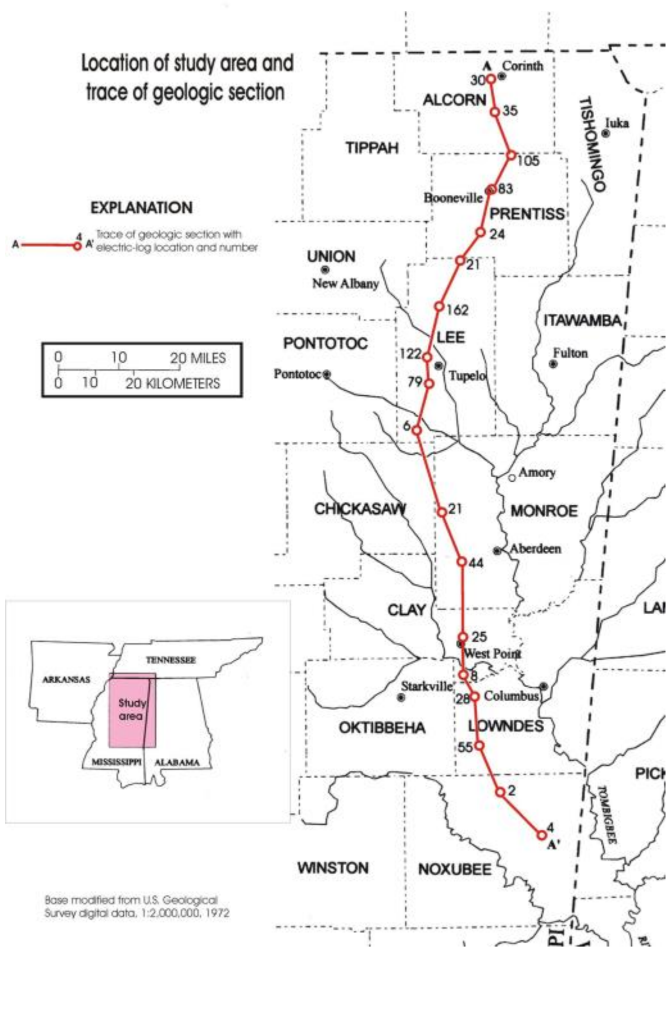


Figure 40. North-south cross section of Paleozoic and Cretaceous units in northeastern Mississippi (at top), showing the overlap of the Tuscaloosa (an important regional aquifer) to the north by the McShan and Eutaw formations and the thickening of the Tuscaloosa to the south, where it contains three members (from Strom, 1998, p. 10).

Figure 41. Location map of wells used in cross section (at left) (from Strom, p. 3).

within the county. Public supply wells, such as the North Hinds Water Association Camp Kickapoo well, often bypass the Cockfield aquifer for the basal sands of the Kosciusko or Sparta aquifer, which yield a high volume of water, as rated in gallons per minute, at a depth of around 1,500 feet. Hinds County is an example of much of Mississippi's coastal plain setting, where water supply associations may choose from more that one aquifer for their water supply needs. This resource is renewable because the state's average rain accumulations total some 50 to 68 inches a year.

The following account is a personal (Dockery) example of the value of a private Cockfield water well. My father recently had expensive dental work done, and the dentist told him not to drink water with a pH lower than 7.0. The dentist then recommended a certain brand of bottle water that had a pH of 7.4. I told my father that the pH of my sister-in-

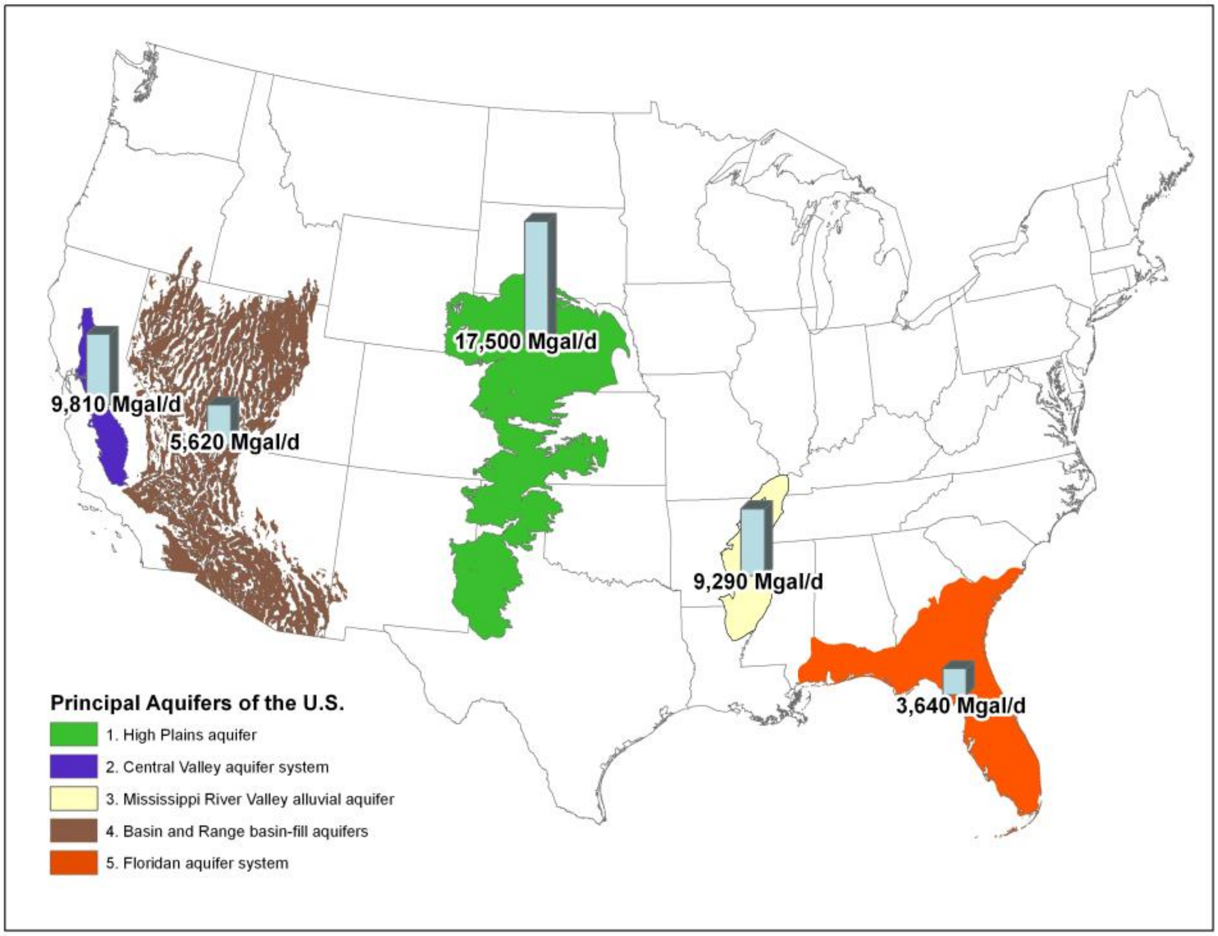


Figure 42. Principal aquifers of the United States, showing the Mississippi River Valley alluvial aquifer as third among the top aquifers in producing 9,290 million gallons of ground water per day. Illustration from Jeannie Barlow, U.S. Geological Survey. Image 2258.

law's Cockfield well was 8.2 and that he could have all of that water he wanted for free.

The hydrology of aquifers such as the Cockfield and Kosciusko formations is complex and cannot be adequately depicted as tabular sheets of sands. In northwestern Hinds County, the lower sections of both formations contain upper and lower aquifer sands. These sands are the skeletal elements of ancient river and delta environments and may merge locally where thick river-channel and distributary-mouth bar sands are present. One such channel sand in the lower Cockfield Formation trends north-south along the Hinds-Warren County line and extends southward to the Copiah-Claiborne County line (Dockery, 1976).

The structural geology of central Mississippi determines the regional distribution of ground-water supplies. South of Interstate 20, formations dip to the south and have surface exposures, or outcrop belts, that trend east-west. North of Interstate 20, a structural trough known as the Mississippi Embayment changes the dip toward the west and causes formations to trend north-south along their outcrop belts. An exception to this is Jackson, Mississippi, which sits atop the Jackson Dome where aquifers dip away from the crest in all directions. Here ground-water supplies in the Cockfield and Sparta aquifers at Jackson can be accessed by wells at a shallower depth but with less draw-down space. Though these aquifers do not presently supply the total needs of the City of Jackson, they are used by surrounding communities and industries, including such specialty needs as the water bottled by the Mississippi Bottled Water Company.

The Alluvial Aquifer, Ground-Water Temperature, Iron Content. Challenges today in modeling ground-water supplies exist in the Mississippi "Delta" and in the Miocene aquifers of southern Mississippi. In the "Delta," the Mississippi River alluvial aquifer is commonly in hydrologic connection with the underlying Cockfield and Sparta aquifers. For this area, mapping the Eocene "bedrock" below the alluvium is important in the hydrologic investigations currently under study by the MDEQ Office of Land and Water Resources (see Jennings, 2001). The base of the alluvial aquifer is irregular, and, in places, the alluvium fills in deep holes left by the ancient course of the Mississippi River, as shown by the mapping work of Saucier (1994b). This irregular surface makes mapping of the Eocene subcrop more difficult.

Recharge of the alluvial aquifer (**Figure 33**) comes from several sources, including local rainfall infiltration and the Mississippi River along its western boundary. However, recharge from the river is possible only when the river is higher than the water level of the alluvium (Bryant and Dowdy, 1998). Potentiometric maps constructed for the Mississippi River Valley alluvial aquifer (Bryant-Byrd, 2002) confirm that the river is not a major source of recharge as once thought (**Figure 42-44**). A more significant source of recharge comes from the truncated Tertiary aquifer sands along the bluff line. These aquifers are in contact with the alluvium and supply it with a constant flow of ground water. Subcropping Tertiary sands are a potential source of recharge for the alluvial aquifer during the irrigation season in the summer months. Rain-swollen, interior streams may also provide a minor periodic source of recharge (Bryant, 1995).

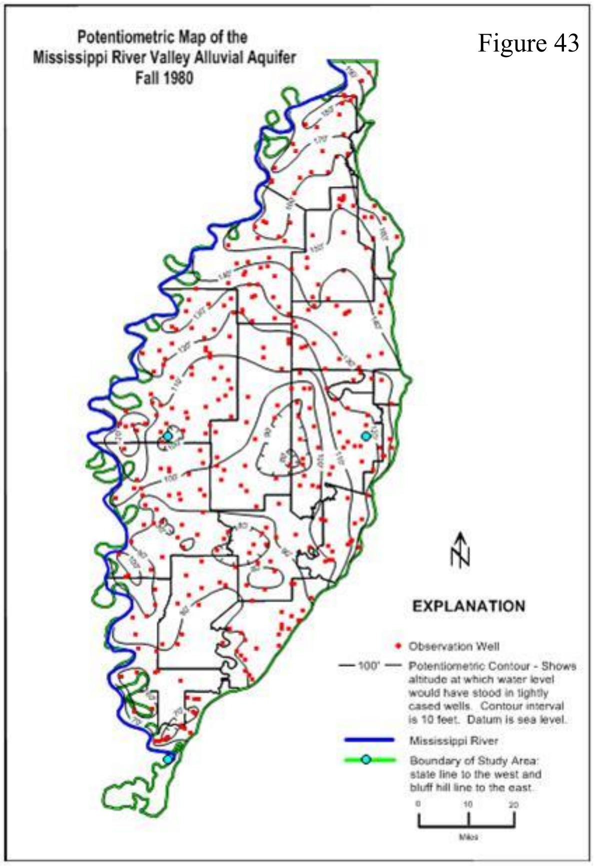
The water temperature of the alluvial aquifer is near the mean annual temperature, ranging from 63° F in DeSoto County to 66.5° F at Vicksburg (Brown, 1947, p. 56). In contrast, Brown (1947, p. 33) noted that a deep "Delta" well at Glen Allen in Washington County produced water from the Eocene Meridian Sand at 1,746 to 1,786 feet at a temperature of 98.7° F and suggested that the heat might come from the buried volcanic terrain of the Sharkey Platform. Leroy Percy State Park in Washington County is the oldest state park in Mississippi and boasts an alligator population that can be safely viewed from a raised boardwalk over their hot artesian water home. This pond is fed by a well (USGS well O-13) completed in 1954 in the Meridian Sand at depth of 1,696 feet. The initial artesian water-level was 100 feet above ground level, and the water had a temperature measured at 36° C, which is equivalent to 96.8° F. In Jackson, Mississippi, above the northwest flank of the buried Jackson Volcano, water-supply wells for Duke Energy's "make up water supply" for the cooling tower of its power plant on Beasley Road encountered water above 100° F in the Meridian Sand at 1,600 feet. A pumping test on the Duke North America #2 Hinds (by Bill Oakley on May 18, 2000), after pumping for 24 hours at 720 gallons per minute from an interval screened at 1,605 to 1,690 feet, showed the water to be as hot as a hot summer's day with a temperature of 39.12° C or 102.4° F.

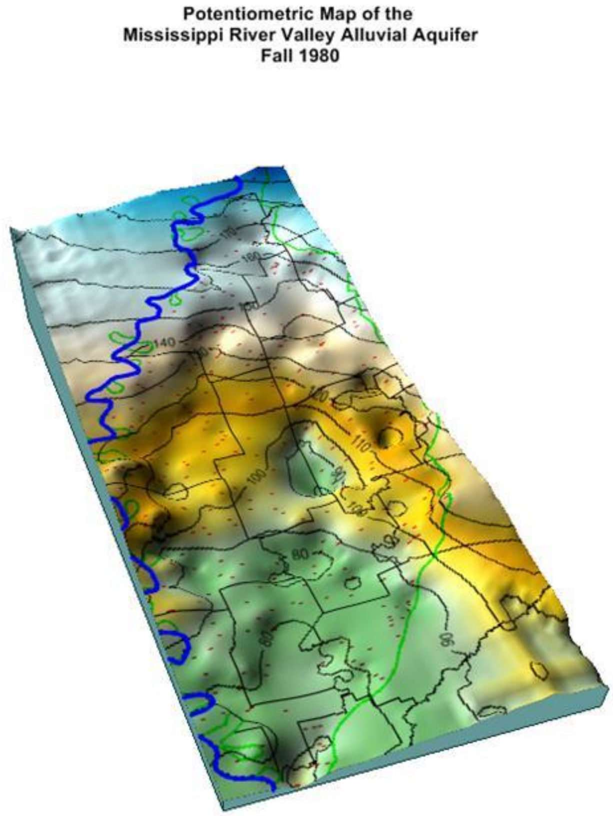
The alluvial aquifer is characterized by a high iron content, which colors the water, stains pipes, and gives the water a bad taste. This is also true for some deep Cretaceous and Tertiary aquifers and shallow Miocene and Pliocene (Citronelle) wells, though not usually to the extent of the alluvial aquifer. One well in the Memphis Sand aquifer of Memphis Well Field has a high iron content and is thought to be in hydrologic contact with the overlying alluvial aquifer. Lovley et al. (1990) explained the role of Fe(III)-reducing bacteria in the release of high concentrations of dissolved iron into anaerobic ground waters of the Atlantic Coastal Plain.

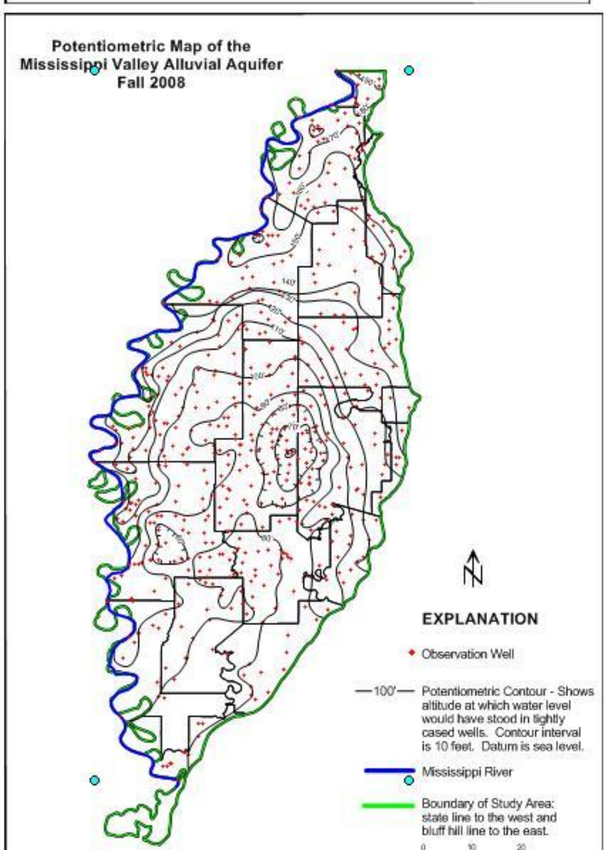
Lusk (1951) studied the connection between the Alluvial aquifer and the Bogue Phalia River at Symonds and Malvina in Bolivar County during the drought of late 1950. He found the discharge of the Bogue Phalia at Symonds to be twice the amount at Malvina, though there was no surface water drainage into the stream between those points, proving the increased flow came from the Alluvial aquifer. The purpose of Lusk's work was to find if the Alluvial aquifer would replenish water pumped from the Bogue Phalia to irrigate rice fields. He noted that many tenant farm houses near the Bogue Phalia were supplied with water from shallow wells drilled to depths of 25 to 40 feet. Water was brought to the surface in these wells by pitcher pumps (hand pumps).

Lusk (1963a) attributed the problem of "desiccation sinking at Clarksdale" as due to drying of alluvial sediments by the cone-of-depression associated with increased pumpage from the Alluvial aquifer during a time of prolonged drought in the early 1950s. Following this drought, damaging settling developed in the Eliza Clark Elementary School building after a prolonged interval of rainfall in 1957. The City of Clarksdale engineer found numerous other depressions in the city, which was underlain by about 160 feet of alluvium. Test pits showed fractures in dried alluvial clay filled with silt and very fine sand transported downward by rainfall from overlying, load-bearing, surficial deposits. Lusk recommended: "For the city of Clarksdale to require that all future wells drilled for air-conditioning inside the city and completed in the alluvial sand

Figure 43


Potentiometric Map of the
Mississippi River Valley Alluvial Aquifer
Fall 1980
EXPLANATION
Observation Well
100' Potentiometric Contour - Shows altitude at which water level would have stood in tightly cased wells. Contour interval is 10 feet. Datum is sea level.
Mississippi River
Boundary of Study Area: state line to the west and bluff hill line to the east.
0 10 20
Miles


Potentiometric Map of the
Mississippi River Valley Alluvial Aquifer
Fall 1980


Potentiometric Map of the
Mississippi Valley Alluvial Aquifer
Fall 2008
EXPLANATION
Observation Well
100' Potentiometric Contour - Shows altitude at which water level would have stood in tightly cased wells. Contour interval is 10 feet. Datum is sea level.
Mississippi River
Boundary of Study Area: state line to the west and bluff hill line to the east.
0 10 20
Miles

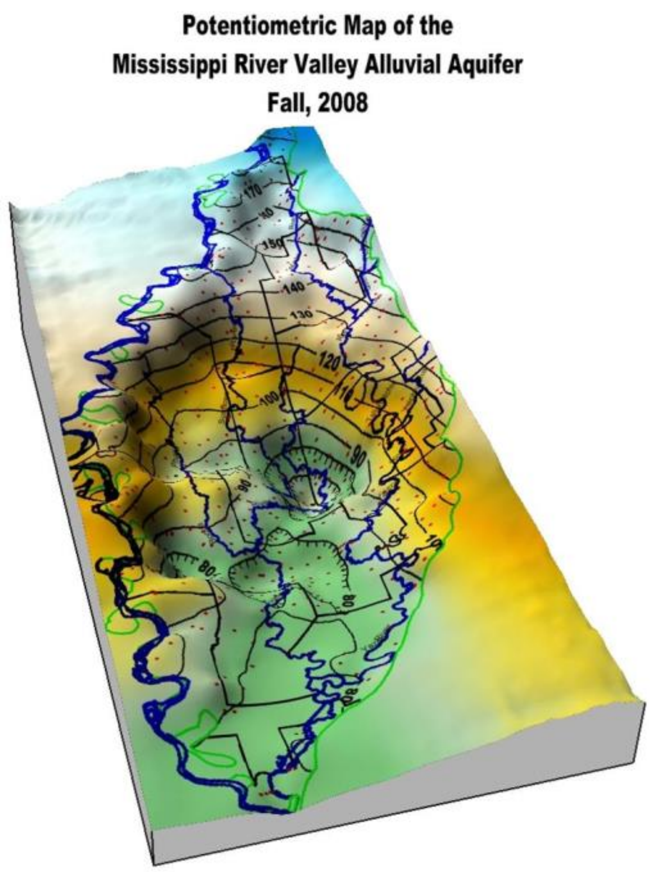

Potentiometric Map of the
Mississippi River Valley Alluvial Aquifer
Fall, 2008

Figure 43. Facing page: Two-dimensional and three-dimensional potentiometric maps, showing the height above sea level of the water table in the Mississippi River Valley Alluvial aquifer for fall of 1980 (top) and fall of 2008 (bottom). Increased pumping over that time period has depressed the water table in the central Delta region (figures from Charlotte Bryant Byrd).

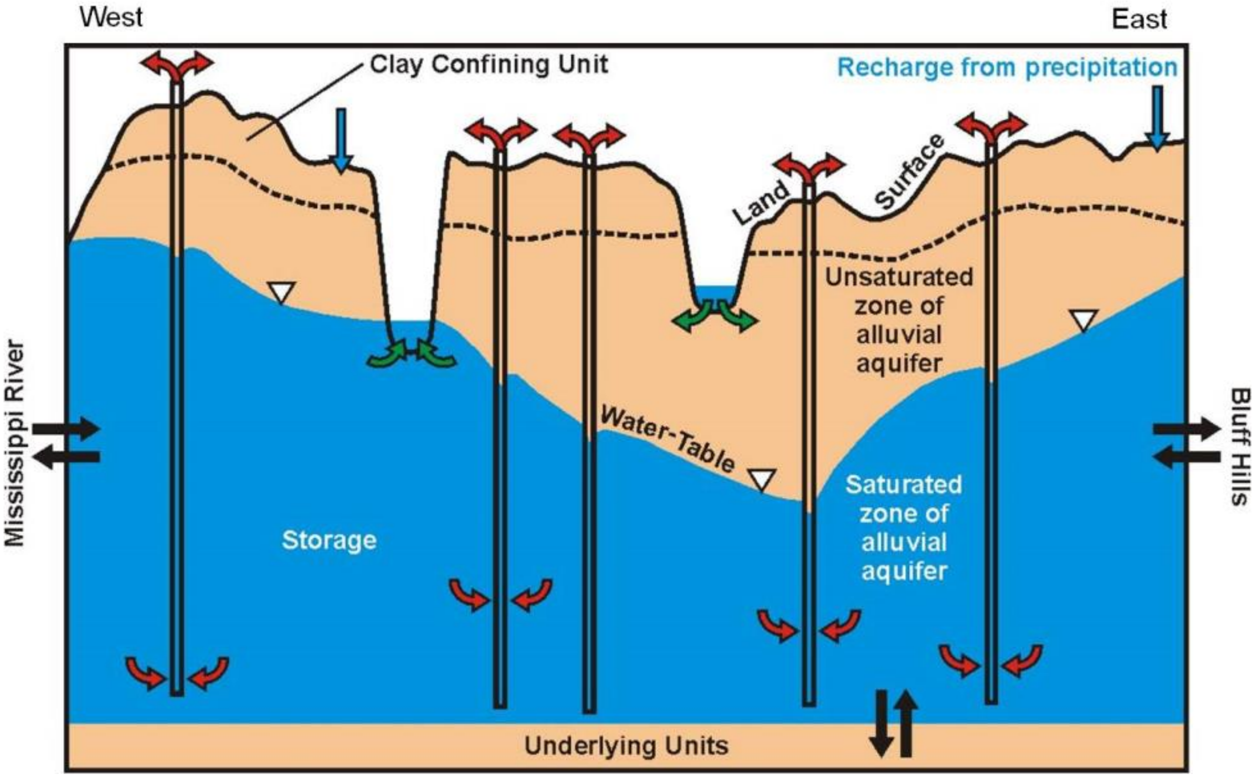


Figure 44. Recharge into the Mississippi River Valley Alluvial aquifer from such sources as the Mississippi River, the Bluff Hills, underlying units, the Bogue Phalia and Sunflower rivers, and precipitation and discharge form irrigation and catfish-pond wells (from Jeannie Barlow, U.S. Geological Survey).

and gravel (down to depths of 160 to 170 feet) to have a second well drilled for the return of the water to the formation."

Southern Mississippi. The problem posed by the Miocene aquifers in southern Mississippi is that they comprise a monotonous Oligocene-Pliocene sequence of sands and clays, which lack fossiliferous marine units and are difficult to subdivide into formations. In central and northern Mississippi, fossiliferous marine formations provide diagnostic fossils, which aid in field mapping and well stratigraphy. In southern Mississippi, where marine fossils are largely absent, geologic mapping and subsurface correlations require the tedious connecting of sand body to sand body as interpreted on oil well and water well geophysical logs and the projection of these sands to the surface. Miocene freshwater aquifers in the highlands of southwestern Mississippi connect with aquifers below the freshwater zone in Baton Rouge and other municipalities in southeastern Louisiana. Based on its oxygen isotope composition, ground water used in Baton Rouge today fell as rain during the Pleistocene Ice Age (Gonthier and Aharon, 1990). Carey et al. (2004) found ground waters in a Miocene sand aquifer on the Alabama Gulf Coast to have ^{14}C ages of 375-6,790 years old and ^{4}He ages of 50-7,500 years old.

Disconformably overlying the Miocene of southern Mississippi are the graveliferous sands of the Pliocene Citronelle Formation. The Citronelle provides the shallow groundwater needs of southern Mississippi, is responsible for many of the state's springs, and supplies gravel resources. Many towns owe their existence to Citronelle springs, and some show this by their name. Crystal Springs is such a town and is also one of the major suppliers of gravel in the state. Most rivers and streams in southern Mississippi are spring fed from the Citronelle Formation, and gravels from the Citronelle are reworked as gravel bars along their

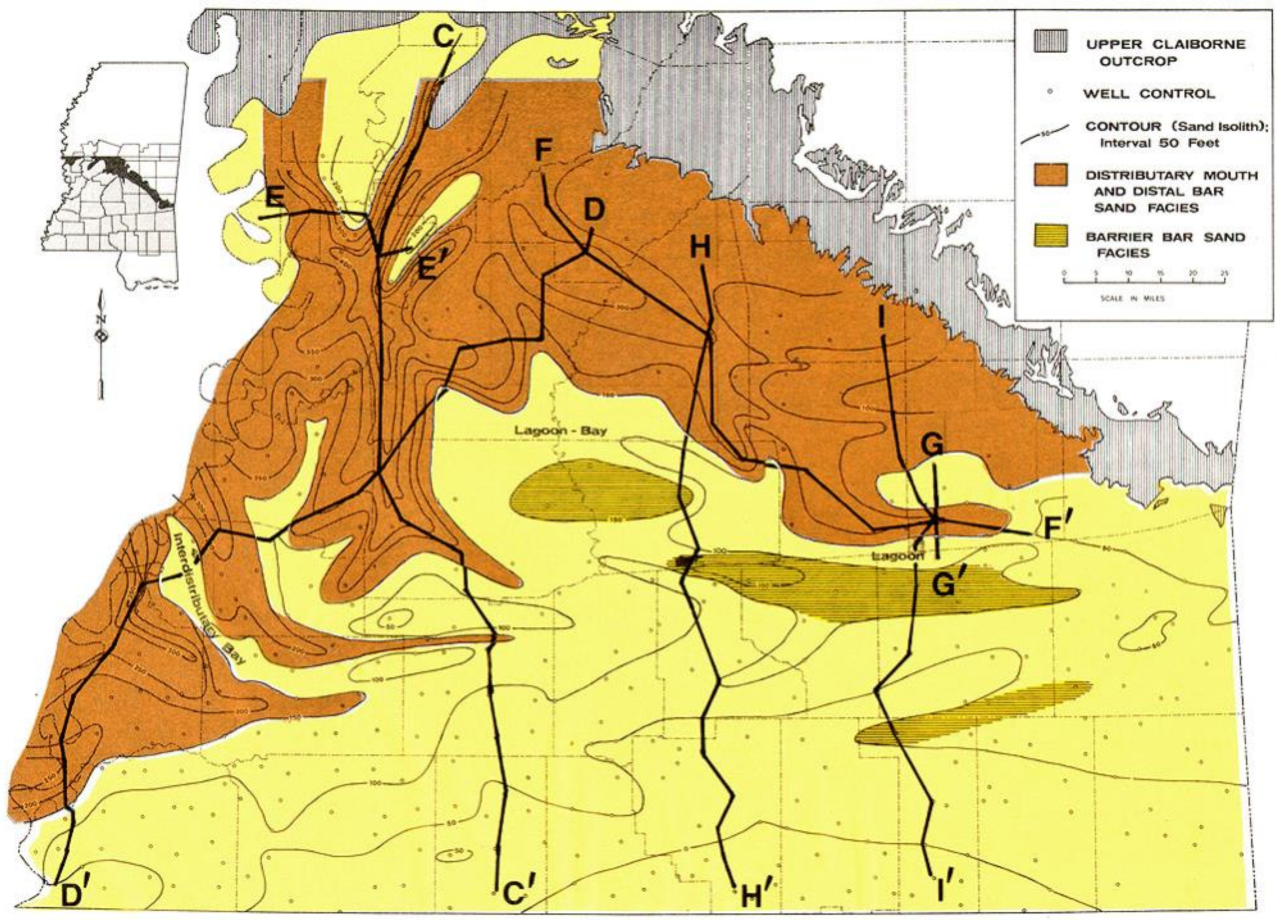


Figure 45. Net sand isolith map, showing delta distributary-mouth-bar sand trend (brown) in the Cockfield Formation of south-central Mississippi and the location of cross section E-E' and other cross section from Dockery (1977). Delta-front sands occur in the north and west, while barrier-bar sands are present in the southeast.

course. One evidence of a Pliocene age for the Citronelle Formation is its elevation. What was once deposited in a river bottom in the Pliocene now caps the highest hills with its basal contact at an elevation of 400 feet above sea level and its upper surface extending to elevations of over 600 feet in Jasper County and at the junction of Simpson, Jefferson Davis, and Covington counties. Situated on the Citronelle Formation just north of McComb, an old railroad town in Pike County, is the town of Summit, which derived its name for being one of the highest points along the railroad between Jackson and New Orleans (Brieger, 1980, p. 397).

Another shallow Pliocene aquifer, known informally as pre-loess terrace deposits, supplies spring-fed streams in western Mississippi along the Mississippi River valley wall and onto the alluvial plain. This aquifer is also graveliferous and is responsible for the gravel bars in western streams and for gravel resources extending from Natchez to Memphis, Tennessee. The pre-loess terrace deposits are similar to gravels at the base of the present Mississippi River Alluvial Plain and probably represent a time in the Early Pleistocene when the course of the combined Mississippi and Ohio rivers flowed at a higher level. After the Pleistocene-Recent Mississippi River Alluvial Plain was down cut to its present level, the Early Pleistocene terrace was left perched on the eastern valley wall where its water table drained into local creeks and streams. These clear-water streams served as a water supply for many early settlements along the bluff line, including Vicksburg, Satartia, Yazoo City, Charleston, and Natchez, where it is called the Natchez aquifer (Boswell and Bednar, 1985). North of Charleston, a string of Mississippi towns lies along the center of the loess and pre-loess terrace exposure belt. These towns direct the path of U.S Highway 51 and Interstate

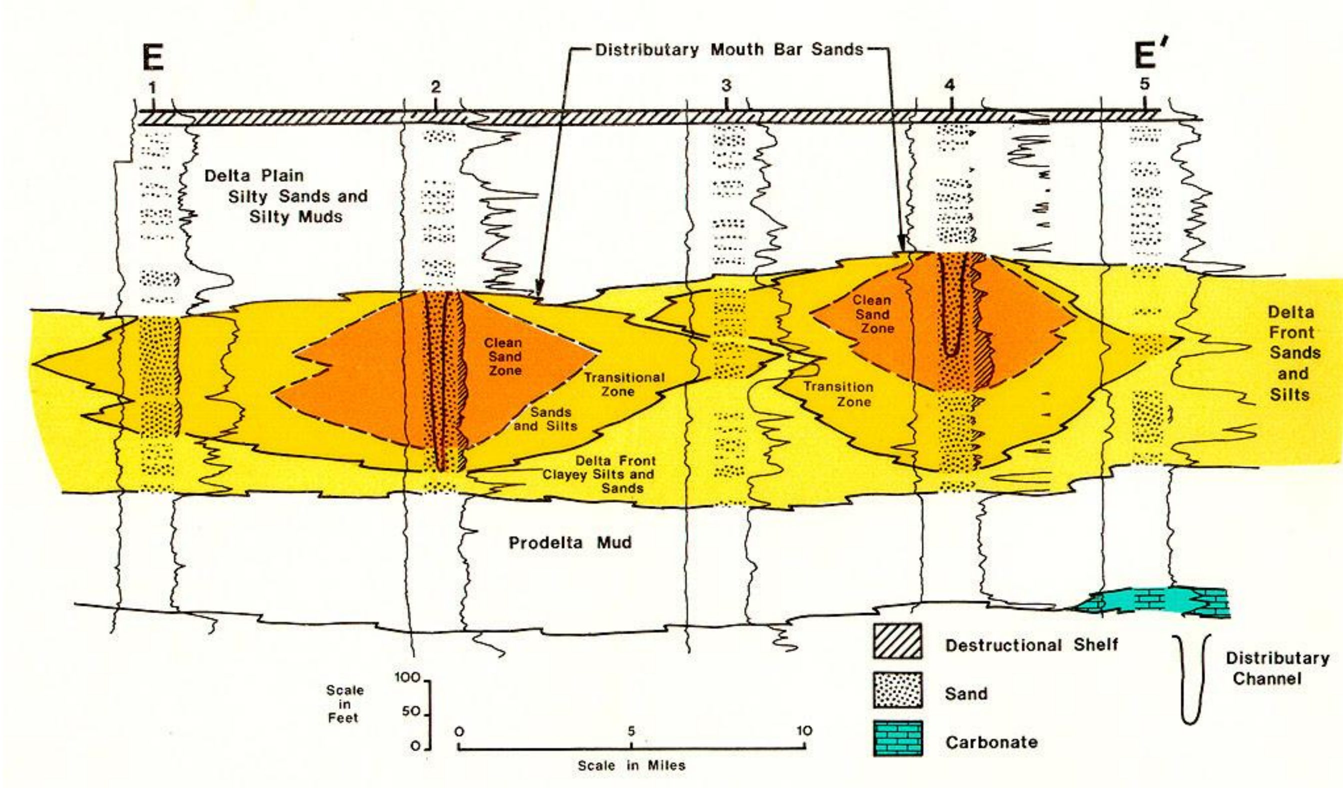


Figure 46. East-west cross section E-E' along depositional strike and across lenticular distributary-mouth-bar sands of the Cockfield Formation in Warren and Yazoo counties, Mississippi (from Dockery, 1976). Water well drilled in the channel sands would have an excellent ground-water supply, while those drilled between the channels would not.

55 to Memphis, Tennessee (also a bluff-line town), and include Oakland, Enid, Pope, Courtland, Batesville, Sardis, Como, Senatobia, Coldwater, Hernando, Nesbit, and Southaven. Today their water supply is derived from deep Paleocene and Eocene aquifers in the Claiborne and Wilcox groups.

Pliocene aquifers also provide fresh water for Mississippi's barrier islands and are potential fresh-water sources even at sea. The upper Graham Ferry aquifer provides fresh water for Ship Island with two wells at 436 and 480 feet and for Horn Island with one well at 835 feet (Stewart and Everett, 2002). Lowe (1915, p. 113, fig. 10) published a photograph of the "flowing artesian well on Ship Island." Brown et al. (1944, p. 52) noted the hydrostatic head at Horn Island to be 49 feet above sea level. In 1928, during prohibition, the Isle of Caprice Amusement and Development Company completed a flowing well (Harrison Co. well #203 of Brown et al., 1944) to a depth of 867 feet in the Graham Ferry aquifer for their popular gambling and sunbathing resort at the Isle of Caprice (originally Dog Island, 11 miles southeast of Biloxi between Horn and Ship islands). When the resort and island were reduced to a sand shoal below sea level in 1932, all that remained above the Gulf waters was the flowing well head, which provided a source of fresh water for local vessels until it corroded and collapsed in the 1970s (Rucker and Snowden, 1988).

Geophysical log analysis of the Sapphire #1 State of Mississippi oil exploration well, an offshore well drilled three miles south of Ship Island, indicates fresh water at a depth of 1,800 feet in the lower Graham Ferry aquifer. Priddy (1955) placed the limit of fresh water in "Miocene" aquifers south of Mississippi's barrier islands. The presence of fresh water lenses below the Gulf of Mexico is a testament to the driving force of hydraulic heads generated in the Pliocene hills of southern Mississippi. However, this fresh water may also be a relic of the last ice age some 11,000 years ago when much of today's shallow Gulf sea floor was dry ground. Freshwater was also encountered 150 kilometers offshore of Long Island, New York, within a shallow Miocene sand at a depth of 100-350 meters below the sea floor, a phenomena attributed by Person et

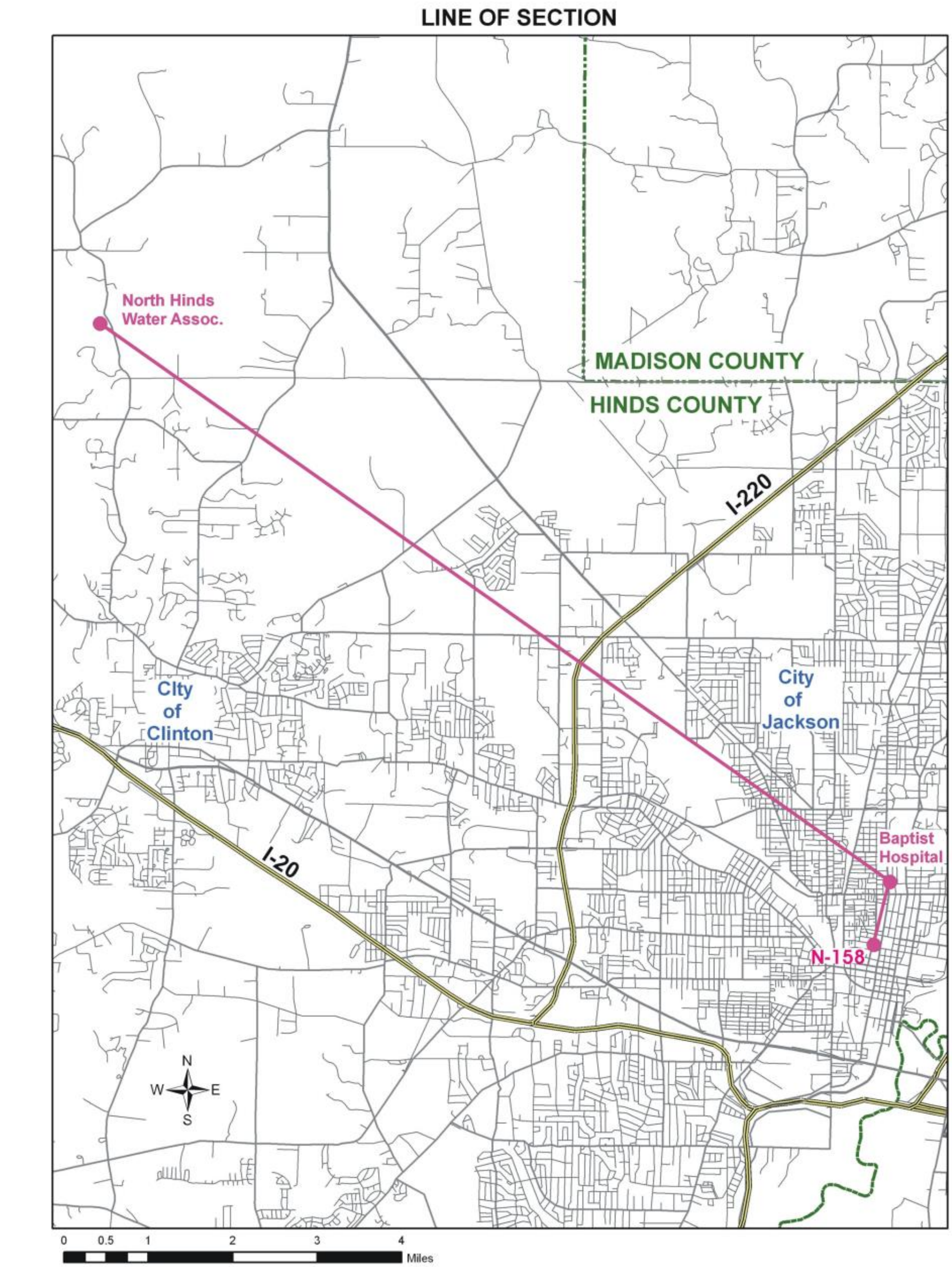


Figure 47. The location of the North Hinds Water Association's Shepherd's Hill water well, the Baptist Hospital water well #1, and the N-158 well and the line of cross section through these wells. Image 1632.

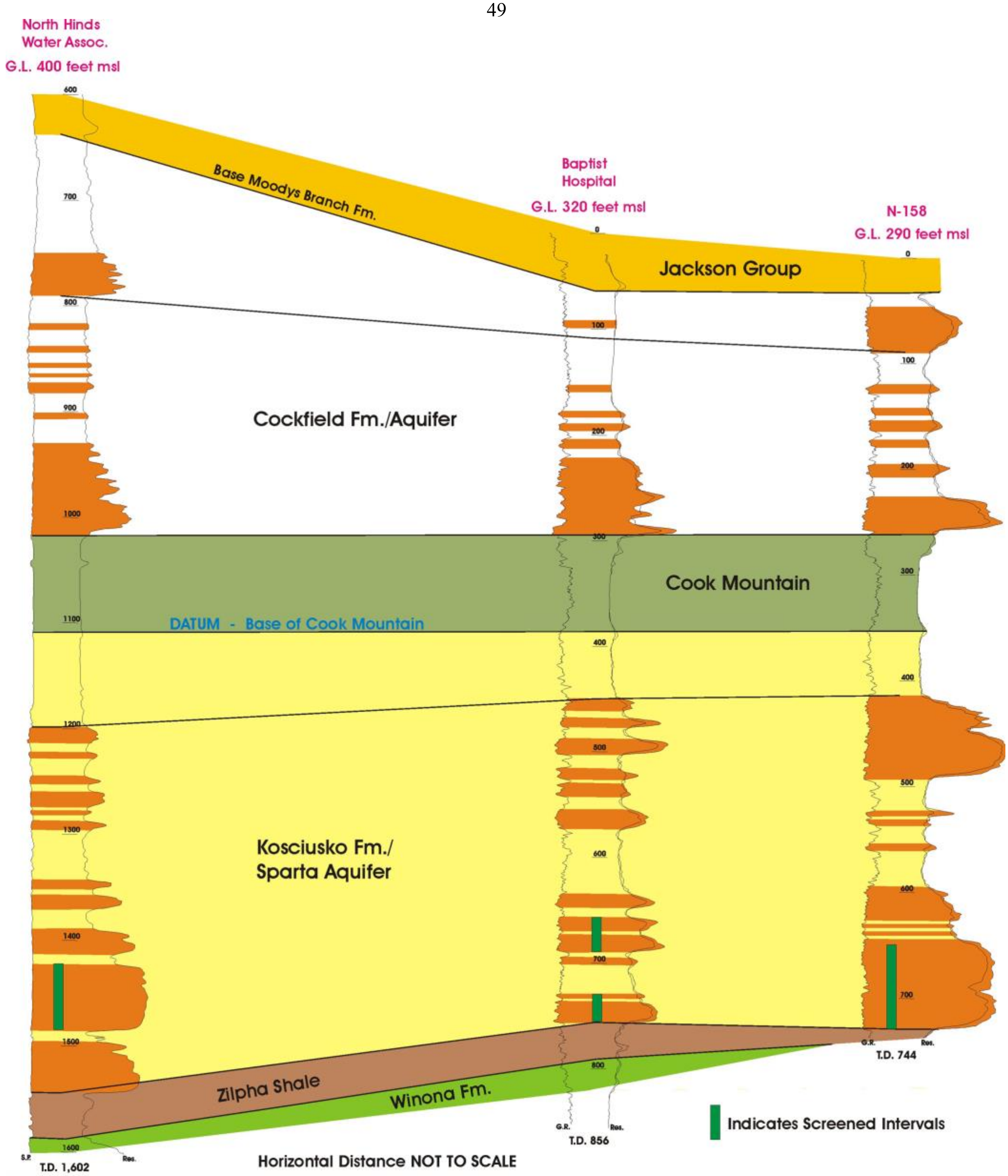


Figure 48. Cross section through the North Hinds Water Association, Baptist Hospital #1, and MDOT water wells, showing the location of freshwater-bearing sands in the Cockfield and Sparta aquifers. Both aquifers have well-developed basal sands and more weakly developed upper sands. The Baptist well lacks both well-developed upper and lower sands in the Sparta, while the MDOT well, not only has both well-developed Sparta sands, but also has well-developed upper and lower Cockfield sands. Image 1633.

Figure 49. Bill Oakley collecting a water sample during the 200-gallon-per-minute pumping test on the Baptist Hospital #1 water well (left); and the water-well temperature and pH measurements (right). Pictures (digital composite; Image 1630) taken on September 7, 2010.

Figure 50. Left, 700-gallon-per-minute pump test of the second Baptist Hospital test well as was taken on January 28, 2011. Right, the Baptist Hospital #2 water well completed with pump and pipes at the well head as was taken on July 14, 2011. Composite Image 1927.

al. (2003) to Pleistocene sub-glacial melting and aquifer recharge beneath the ice sheet that once covered New York. Offshore aquifers may also be flushed with fresh water due to discharge along a fault or the walls of a submarine canyon (Groen et al., 2000).

Ground Water and Depositional Systems

Mississippi's ground-water supply is often a matter of location, location, location. **Figure 45** is a net sands isolith map for the Middle Eocene Cockfield aquifer in central Mississippi (from Dockery, 1977). Geometries of sand-thickness trends depicted on the net sands map were used to map fluvial (river) and delta systems and offshore barrier bar sands. These same geometries depict the groundwater plumbing of the Cockfield aquifer, an important source of groundwater across central and northwestern Mississippi. Thick net-sands trends, indicating the presence of fluvial channel sands and delta distributary mouth bar sands, are depicted in brown. A major north-south fluvial-channel sand trends from Yazoo County southward along the Warren-Hinds County border and along the Claiborne-Copiah County border. Another sand trend extends northwest-southeast from the Hinds-Madison County border to southwestern Jasper County. East-west cross section E-E' in **Figure 46** shows two channel sands in wells 2 and 4; well 4 is bracketed by sand-poor flood-plain deposits in wells 3 and

Figure 51. Lignite seams bend beneath a fluvial channel sand (upper right) in the middle Tuscahoma Formation, which cuts out the I and H2 lignites seams of the lower Tuscahoma. The red cable carries 60,000 volts to power the dragline. Picture (color negative 531-16; Image 325) taken on November 11, 2004.

5. Water wells drilled in the channel sands would have an excellent groundwater supply, while those drilled between the channels would not.

Figure 47 shows the location of the recently drilled Baptist Hospital and N-158 wells in Jackson, Mississippi, and the North Hinds Water Association's Shepherd's Hill water well north of Clinton, Mississippi, drilled in 1990. All three wells get their water from the Sparta aquifer, the aquifer below the Cockfield aquifer, as shown in the cross section of **Figure 48**. The North Hinds well was screened in the basal Sparta sand at a depth of 1,420-1,480 feet and had a water temperature of 88.7 degrees F and a pH of 8.9. Today this well pumps water at a rate of 612 gallons per minute with a submersible pump. **Figure 49** shows Bill Oakley collecting a water sample during a 200-gallons-per-minute pumping test on the first Baptist well. The water sample had a temperature of 28.6 degrees C (83.5 degrees F) and had a pH of 8.7. The Baptist well was drilled between channel sands in the Sparta aquifer and had to be screened twice at 658-689 feet and 729-756 feet to provide a sufficient water supply. The recommended pumping rate for this well is 300-400 gallons per minute. Based on the water temperature, it is likely that most of the water supply is coming from the deeper screened interval. Baptist Hospital is now drilling a second well on the northwest corner of their property along North West Street to increase their water supply.

. **Figure 50** is a composite image that shows (at left) the pump test for the second Baptist Hospital well, which drilled into a thick basal channel sand in the Sparta Formation. At right, the figure show the completed well head with pump and pipe fittings. The 24-hour test was run at a rate of 700-gallons-per-minute. This well has a recommended pumping rate of 1,000 to 1,200 gallons a minute. An example of a channel-sand deposit is given in **Figure 51**, which shows a channel sand in the middle Tuscahoma Formation exposed at the Red Hills Lignite Mine in Choctaw County, Mississippi. The channel sand cuts out lignite seams in the lower Tuscahoma Formation and rests on the underlying Nanafalia Formation. Ground water in the middle Tuscahoma channel has caused slope instability and has been a problem at the mine site.

JACKSON'S WATER CRISIS, FEBRUARY 2010

This article is from the June 2010 issue *Environmental News* (Dockery, 2010, p. 21-25)

The following is a verse from *The Rime of the Ancient Mariner* by Samuel Taylor Coleridge that has been changed by just a word (in bold) to explain Jackson's water crisis of January 2010.

Water, water, everywhere

And all the **pipes** did shrink;

Water, water, everywhere

Nor any drop to drink.

When Jessica Larche of Jackson's FOX40 News asked me for an interview concerning Jackson's broken water mains and the shifting Yazoo Clay, I was prepared to blame a combination of cold weather and the Yazoo Clay as the problem. After all, the clay does plenty of structural damage when it gets wet and swells; how much more damage could it do if the wet clay froze, and the water expanded another 9%. In preparation for the interview, I studied up on the damage done by cold-weather geologic processes such as frost heaving and ad-freezing. Ad-freezing requires a clay-rich soil such as the Yazoo Clay. When the upper clay layer freezes, water is drawn by capillary action from the clay below, adding to the ice at the top and increasing the soil thickness by as much as 30%. Such wintertime freezing in more northern climates can lift foundations. For this reason building inspectors require that foundations be built below the frost line, the average depth of winter freezing in that area. Even with deep foundations, frozen soil can freeze to unheated basement walls and lift the walls above their foundations.

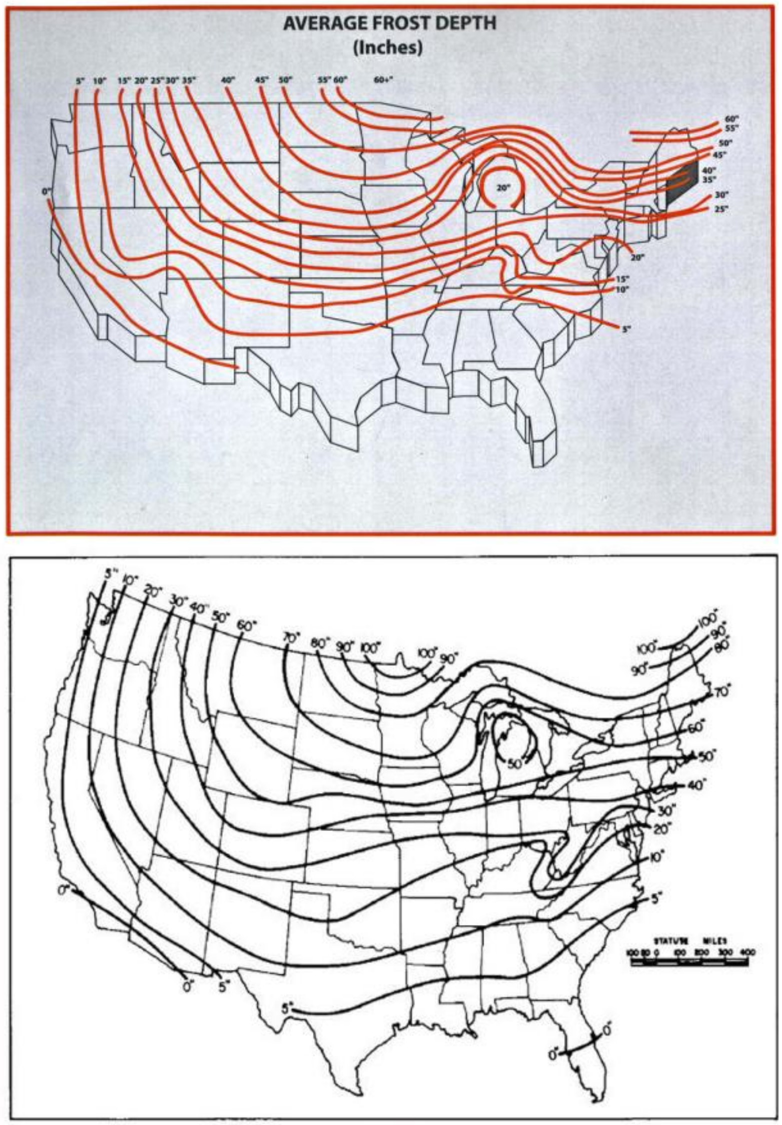


Figure 52. Top, average frost depth in inches; bottom, extreme frost penetration in inches based upon state average from the National Geodetic Survey, NOAA.

I ran some of my ideas about frozen clay and broken pipes by Eddie Templeton with Burns Cooley Dennis, Inc., Geotechnical and Materials Engineering Consultants. Eddie cautioned me that the Yazoo Clay was only part of the problem; the main problem was cold surface water running through the pipes. In my thinking, the cold water could only be 32 degrees F; while frozen ground could be much colder. I tried in several email exchanges to bring Eddie over to my side. One reason I believed frozen Yazoo Clay was the problem was that I had heard and read so many times that the cold weather caused the clay to shift and the pipes to break. Checking online, I found the same thing said in other cities plagued with water main breaks. The maps shown in **Figure 52** are the reasons I conceded. The frost line in Mississippi in a normal winter is much less that 5 inches deep (**Figure 52**, top), and in a severe winter is at best 5 inches deep (Figure 1, bottom). Even in especially severe cold spells, the depth of frozen ground increases at a rate of only one inch per

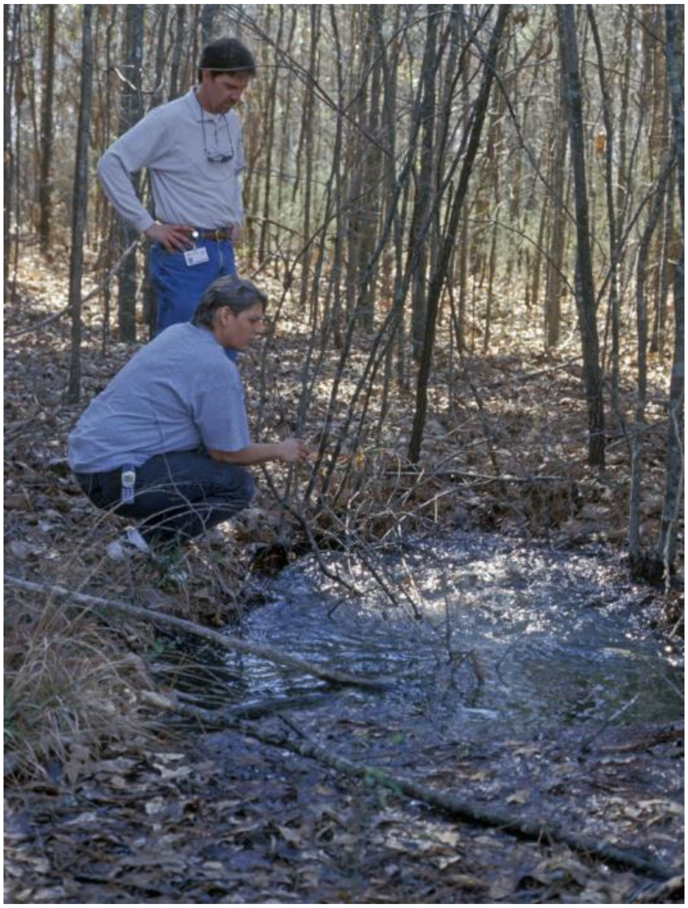


Figure 53. Meg Myers and Ken McCarley inspecting a supposed spring with 82 degree F water on a hilltop in Rankin County. The "spring" proved to be a broken 2-inch water line. Picture (slide 348-7) was taken on February 13, 2002.

these cities had warm water running though their water mains. Though well water is pumped into water tanks exposed to cold air, it doesn't stay there long enough to cool down much. One example of this was a supposed spring I (and others) inspected in Rankin County on a cold day on February 13, 2002. The problems with this spring were that it was on a hilltop rather than at the base of a hill, and the water was warm (**Figure 53**). We were told that the spring had been there some 20 years; it had carved a significant ravine down the hill side. Spring water in central Mississippi has a temperature of about 65 degrees F, the ambient temperature of shallow aquifers in the region. The "spring" water we measured with a laboratory-grade mercury thermometer was 82 degrees F. When we reported this to Wilbur Baughman, a water-well contractor who once worked for the Mississippi Geological Survey and wrote the Rankin County Geology Bulletin, he said "That's Sparta water," Sparta being the name of a deep aquifer. We notified the Greenfield Water Association of our findings; they later found the "spring" to be a break in one of their 2-inch pipes.

Unlike groundwater, the surface-water temperature of Jackson's water supply from the Ross Barnett Reservoir is highly variable. The reservoir is a very large lake, but with an average depth of only ten feet. When I told Jessica that

day. I had no good explanation of how five inches of frozen ground could break a water main buried four feet below the surface. Then I found that other engineers I talked with agreed with Templeton that the especially cold surface water running through Jackson's water mains caused the old, brittle, cast iron pipes to shrink and break. One of those who agreed with this explanation was Rob Ritchey; Rob worked for Jackson's Public Works Department for 18 years before working for the City of Clinton's Public Works the last 9 years.

One question Jessica asked in the interview (on February 19, 2010) was why were the Jackson water mains breaking and not those of the surrounding cities? The answer I gave, which was not aired, was that surrounding cities use groundwater for their water supply. Deep water wells produce water with temperatures ranging between 80 degrees F and 90 degrees F and sometimes higher; so

Figure 54. Cell phone picture taken by a duck hunter of frozen water at Pine Islands on the Rankin County side of the Ross Barnett Reservoir. Picture taken by James Starnes at about 8:00 a.m. on Tuesday, January 12, 2010, after state employees were sent home on Monday at noon.

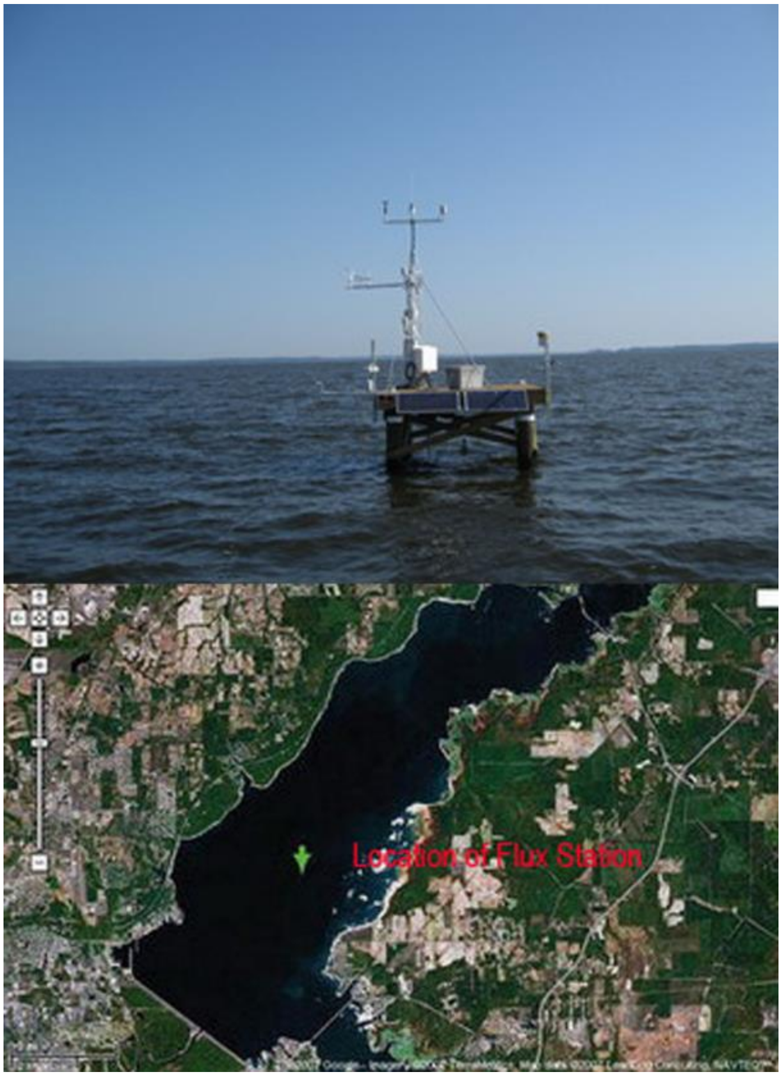


Figure 55. Top, the Ross Barnett Reservoir Flux Station operated by the Micrometeorology Laboratory at Jackson State University in collaboration with the Pearl River Valley Water Supply District; Bottom, location of the station within the reservoir.

cold reservoir water was the reason that Jackson water mains shrunk and broke, she was surprised and said she hadn't heard that explanation before (nor had I before I prepared for the interview).

The Ross Barnett Reservoir was partially frozen over (**Figure 54**) during a 67-hour period below freezing from January 7 through January 10, 2010. To find the actual water temperature at the intake of Jackson's water system, I used information from Jackson State University's Ross Barnett Reservoir Flux Station operated by Dr. Helping Liu and his team of the Department of Physics, Atmospheric Sciences, & Geoscience. With support from the Pearl River Valley Water Supply District, the JSU station was established in August of 2007 by the university's Micrometeorology Laboratory and is located in the middle of the reservoir. It measures air temperature, wind speed and direction, and water temperature at three depths (**Figure 55**). **Figure 56** is a chart of air and water (at three depths) temperatures for the Ross Barnett Reservoir from January 1, 2010, to February 20, 2010. Each tick along the horizontal bottom line marks a five-day period. The chart shows about a three-day lag between the coldest air temperatures and the coldest water temperatures. After air temperatures fell below -5 degrees C on January 7, the reservoir water temperature fell to about 3 degrees C on January 10. Governor Barbour issued a State of Emergency declaration at noon on Monday January 11, due to broken water mains and the loss of water pressure in the City of Jackson, and sent state employees home.

In the spring and summer of 2010, new downtown water-well drilling was contracted with the Donald Smith Company to drill the Baptist Hospital #1 well and the N-158 well (**figures 57-58**). These wells tapped the Sparta aquifer at a depth of 800 feet to provide a dependable water supply for downtown establishments, should there be a repeat of the February water crisis.

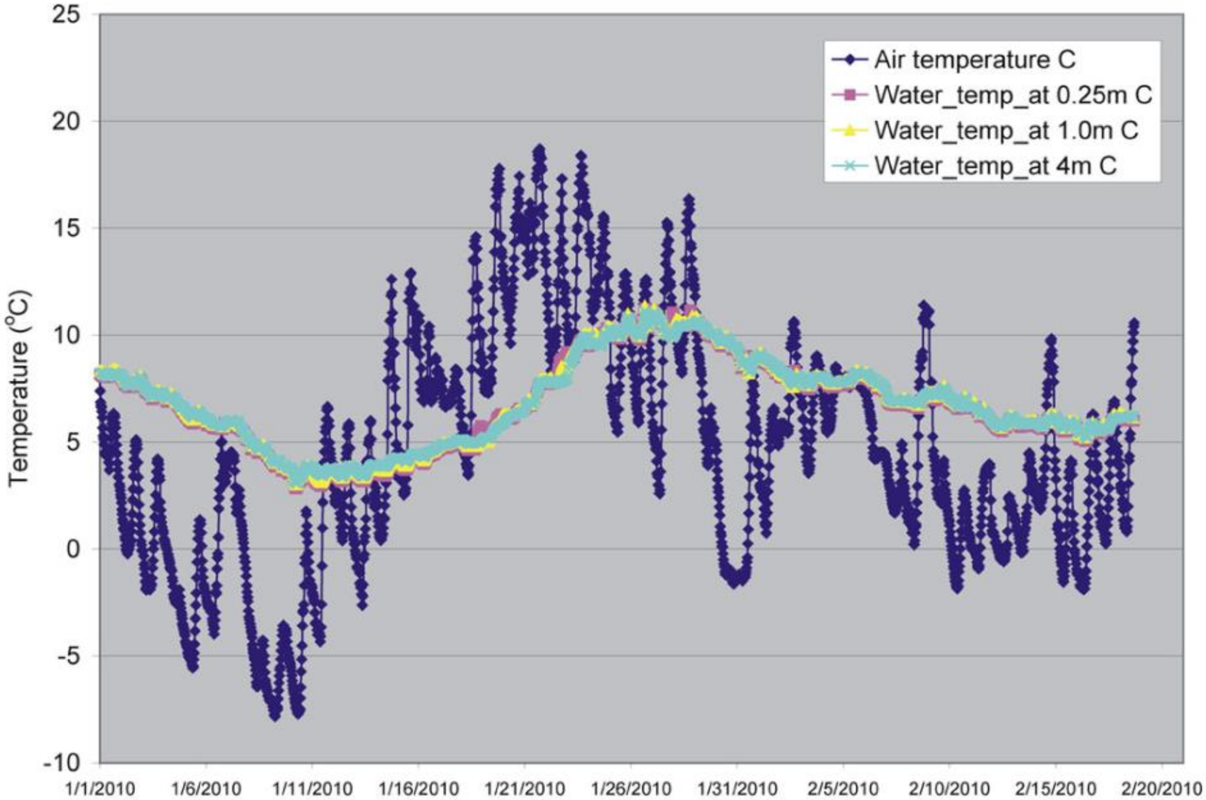


Figure 56. Air temperature in dark blue and water temperature in light blue (at 4 meters depth), yellow (at 1 meter depth) and purple (at 0.25 meter depth) in degrees centigrade [C]. Record from the Ross Barnett Reservoir Flux Station from January 1 to February 20, 2010.

Figure 57. Drilling of an eight-hundred-foot-deep well in the Sparta aquifer by Donald Smith Company for the Baptist Hospital. Picture (digital: Image 1551) was taken on June 22, 2010.

Figure 58. Drilling of the N-158 well, an eight-hundred-foot-deep well in the Sparta aquifer by the Donald Smith Company. Picture (digital; Image 1552) was taken on July 22, 2010.

2018 JACKSON MISSISSIPPI WATER CRISIS

This article is modified from the Feburary 2018 issue of the *Mississippi Geological Society Bulletin* (Dockery, 2018, p. 6-10).

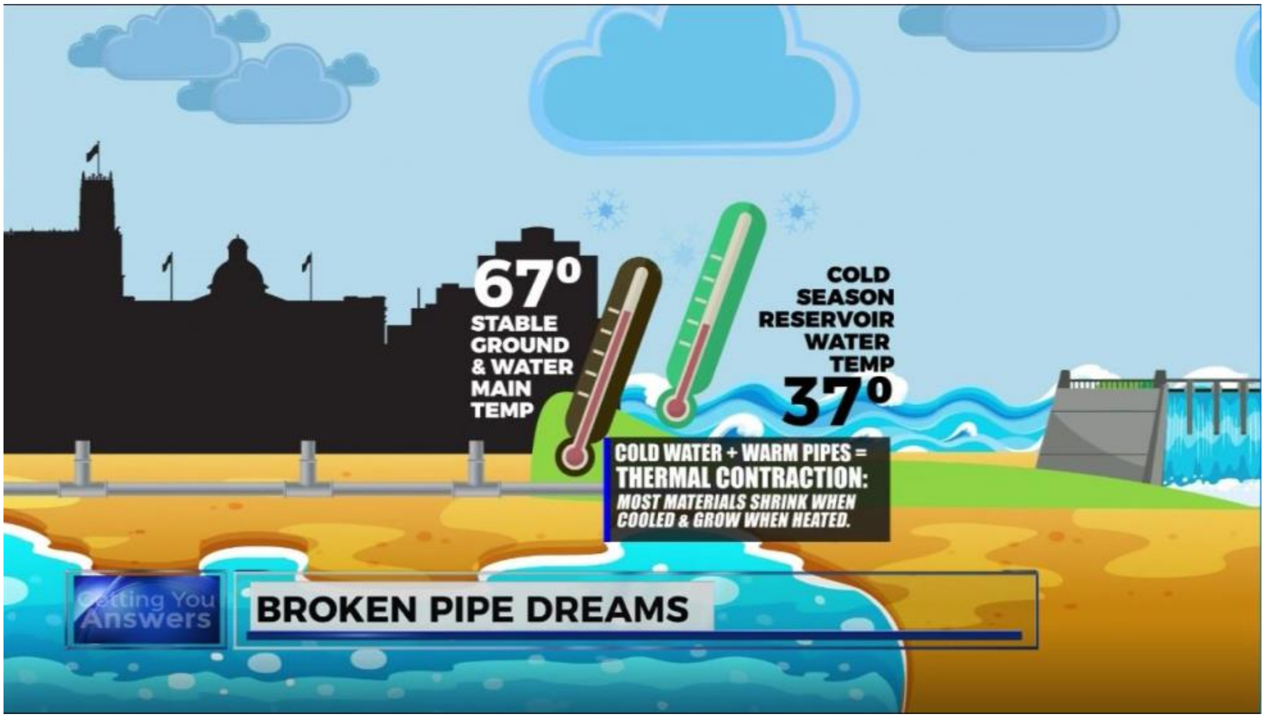
A repeat episode of water main breaks occurred in January of 2018, after a high of only 30 degrees and low of 17 degree F on the 1st and a high of 35 and low of 14 degrees on the 2nd, water mains began breaking in north Jackson, followed the next day by water main breaks in south Jackson. According to the Jackson Weather Service, reservoir water fell to a low of 2.9 degrees C in the early morning of January 3rd. State Offices were closed due to lack of water pressure on the 3rd and due to snow on the 16-17th (**Figure 59**). On January 19, 2018, WJTV 12 News anchor Melanie Christopher called for an interview on the water crisis, which was scheduled through MDEQ PR for January 23. Though there was no initial phone interview, Christopher revealed some of her questions, including, "If cold water from the reservoir is breaking water mains in Jackson, why aren't the water mains breaking in Cleveland, Ohio, which gets water from Lake Erie." In checking on that question, I found this, "Extreme cold triggers more than a dozen Cleveland water main breaks," posted by Chris Anderson, January 2, 2018, 4:46 am. So cold water was breaking water mains in Cleveland (also in Detroit, Michigan, which gets water from the Detroit River and Lake Huron).

Figure 59. Frozen lake north of Clinton, Mississippi, on January 17, 2018.

At a depth of 30 feet, the ground temperature is constant year round. At a depth of 6 feet, the ground temperature may vary 10 degrees F colder or warmer than the mean earth temperature. The mean earth temperature in the Great Lakes region is around 47 degrees F. The mean earth temperature at Jackson, Mississippi is 67 degrees F, some 20 degrees warmer. As water freezes at 32 degrees F in both areas, Jackson experiences a much greater swing in water temperatures. If 37-degree F water at 10 degrees below mean earth temperature is breaking pipes in Cleveland, then 37-degree water should really be breaking pipes in Jackson at 30 degrees below mean earth temperature. At a temperature increase of 30 degrees C, a 10-meter-long steel water pipe will expand 4 mm. The increase with additional footage of pipe is not linear; a 300-meter steel pipe will expand 105 mm. PVC pipe expands even more with a 300-meter pipe expanding 1,800 mm. A water temperature of 30 degrees F is roughly equivalent to 15 degrees C, so cutting the expansion in half, a 984-foot-long (=300 meters) steel water pipe would expand 52.5 mm or 2 inches. Working backwards, a 984-foot-long steel water pipe would shrink 2 inches if

Figure 60. Interview with WJTV's Melanie Christopher on left and MDEQ's 700 North State Street Building on right as shown in the *Broken Pipe Dreams* news story, which aired on February 15, 2018, evening news..

cooled by 30 degrees F. All the pipes in the City of Jackson are thus pulling against each other with this shrinkage. **Figure 60** (left) is a picture of the WJTV 12 News interview taken by Robbie Wilbur. **Figures 61** (right) and 53 are clips for the news story, which aired on WJTV Evening News at 10:00 pm on February 15, 2018.



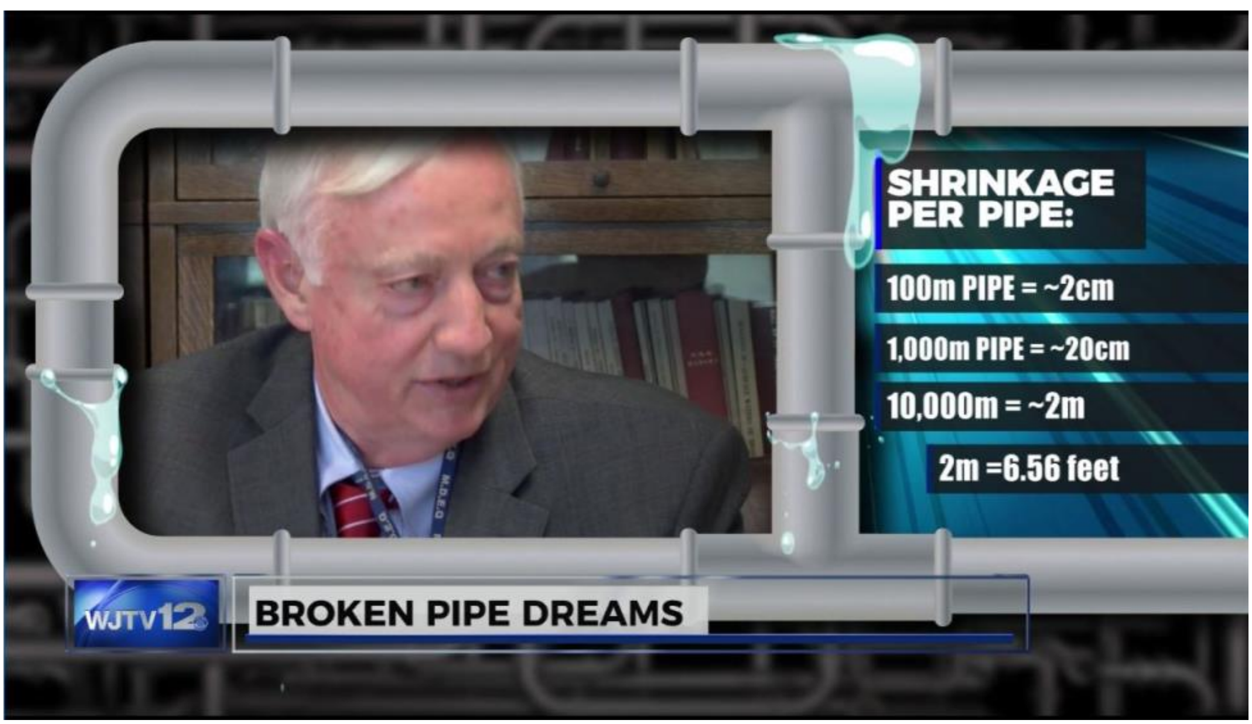


Figure 61. Clips from WJTV's Feburary 15, 2018, Evening News story *Broken Pipe Dreams*. The clip at top show the difference in winter ground temperture and Reservoir water temperture, and the clip at bottom shows the magnitude of pipe shrinkage.

LEAD IN PUBLIC WATER SUPPLIES.

The Mississippi Department of Health Water Supply Division prefers at pH of 8.5 for public water supplies. This pH value decreases corrosion of water supply lines and the service lines connected to them (**Figure 62**). Corrosion of lead service lines or lead soldered copper lines can result in high lead in drinking and cooking water.. Nearly all homes built before 1980 have lead solder connecting copper pipes and some have 100% lead pipes. In a high pH value environment, lead and copper pipes build up an oxide layer over time that protect water from lead or copper contamination. A water supply with a lower than recommended pH can strip the oxide lining and associated scale in service lines and increase lead levels in the water.

Flint, Michigan Water Crisis. The following account is from CNN Library, *Flint Water Crisis Fast Facts*, updated April 10, 2017, and other sources. In 2011, the state of Michigan took over finances for the City of Flint when the city was projected to have a $25 million deficit. The state diverted money from Flint's water supply fund, which was $9 million in the red, to make up shortfalls in its general fund. In April 2014, state managers switched the water source for Flint from the Detroit Water and Sewerage Department to the Flint River (a water source later found to be 19 times more corrosive than Detroit) as a money saving option. This ,plus insufficient water treatment (official failed to apply corrosion inhibitors to the water), potentially exposed 100,000 residents to high levels of lead in their drinking water. The problem stemmed from the corrosion of lead service lines connected to the city's public water supply lines. In October 2014, the General Motors plant in Flint stopped using the city's water because it was corroding engine parts. The company moved to purchase water from Lake Huron from a neighboring township.

On January 21, 2015, the Detroit Free Press reported that Flint children were developing rashes and suffering from mysterious illnesses. An Environmental Protection Agency test of the Flint home of Lee-Anne Walters and her four sick children found tap water with 104 part per billion of lead, nearly seven times the EPA limit of 15 ppb; the test was made known to the state on February 26, 2015. A follow up test on March 18, 2015, found the level at 397 ppb. An EPA manager issued a "High Lead Levels in Flint" memo on June 24, 2015, after Virginia Tech tested the Walter's tap water and found the lead level as high as 13,200 ppb (Water contaminated with 5,000 ppb of lead is classified as hazardous waste).

On September 24, 2015, Dr. Mona Hanna-Attisha of the Hurley Medical Center released a study showing that the number of Flint children with elevated lead levels in their blood doubled after the city switched its water source. Children with blood lead levels of concern (at or above 5 micrograms per deciliter of lead in blood) rose from 2.5% in 2013 to as much as 5% in Flint in 2015. The number of children exposed to lead due to the switch in water supply sources was as many as 6,000 to 12,000. Even low levels of blood lead have been shown to affect IQ, ability to pay attention, and academic achievement. Effects of lead exposure are irreversible. On October 15, 2015, Michigan Governor Rick Snyder signed a bill for $9.35 million to re-connect Flint to Detroit water; the switch was made the next day.

On January 5, 2016, Governor Snyder declared a state of emergency in Genesee County; on January 12, the Michigan National Guard is mobilized to help distribute clean water. On January 13, the governor announced an outbreak of Legionnaires' disease occurring in the Flint area between June 2014 and November 2015, with 87 cases and 10 deaths, which were possibly linked to the water switch. Flint residents were instructed to use bottled or filtered water for drinking. On January 14, Governor Synder wrote President Obama, requesting the declaration of an expedited major disaster in Flint to install lead-free pipes throughout the city at an estimated cost of $55 million.

The U.S. House of Representatives passed a $170 million stopgap spending bill for repairing and upgrading Flint's water system on December 8, 2016. The bill was approved by the Senate the next day. The bill allotted $100 million for infrastructure repairs, $50 million for health costs, and $20 million for loan costs related to the crisis. On January 24, 2017, the Michigan Department of Environmental Quality reported to Flint Mayor Karen Weaver that 90% of Flint water samples contained 12 parts per billion or less from July 2016 to December 2016; thus the city had achieved a level below the federal action level for lead of 15 parts per billion. Even so, the only safe lead level in water is 0%.

Jackson, Mississippi, Water Crisis. In August of 2014, the City of Jackson, Mississippi, took the city's Maddox Road Well system (serving much of south Jackson, with 6 groundwater wells along the Highway 18 corridor, and the City of Byram) off the well system and onto surface water as a cost saving measure (**Figure 63**). The 2012 Annual Drinking Water Quality Report for the City of Jackson Maddox Road Well Water System reported lead levels of 2 parts per billion at the 90th percentile. In the 2014 Annual Drinking Water Quality Report for the City of Jackson Water System, lead levels for unitized Maddox Road-Jackson system (**Figure 64**) at the 90th percentile was 14 parts per billion, just under the federal action limit of 15 parts per billion. The high pH of well water (above 8) had protected service lines connected to the Maddox Road Well system from corrosion and exposure to lead contamination from lead pipes. Surface water from the Ross Barnett Reservoir has a pH of just above 6. This pH is much lower than that of the Flint, Michigan, public water supply after it switched to water from the Flint River; that water after treatment had a pH of 7.4. One relatively new downtown building in Jackson had tap water with a consistent pH of 6.3 for 2016.

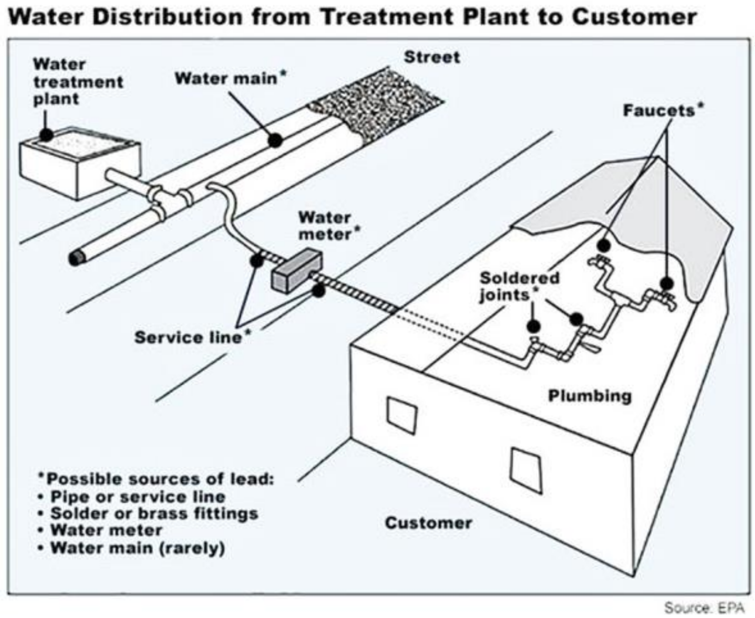


Figure 62. EPA image used by Anna Wolfe's Clarion-Ledger article on March 24, 2016, entitled: "At the tap: Jacksonians deal with lead in water," to show possible sources of lead contamination in Jackson water. Image 2532.

A February 5, 2016, article by Josh Sanburn in *Time* entitled "Another U.S. City Finds Lead in Its Drinking Water" reported that 13 of 58 homes tested in Jackson, Mississippi, had lead levels between 17 and 20 parts per billion, a level above the trigger federal action level of 15. Some of these home were in southwest Jackson (i.e. the Maddox Road Well system). After these tests in June 2015, the City of Jackson switched the Maddox Road system back to well water the following month. However, the Mississippi Health Department did not report the information to the city until January 28, 2016. The reason given to *The Clarion-Ledger* by a State Health Office in an article posted on January 29, 2016, was that the Health Department was not required to give immediate notification. The office added, "Now let me assure you that we're going to take a look at how that's done and see if we don't need to change that."

The *Clarion-Ledger* January 29 article also interviewed Dr. Robert Cox, director of Mississippi Poison Control, who said those who live in the area should be tested: "There are 13 homes where they have elevated levels, but they have hundreds of homes right next door and right down the street that we have never tested. There is no safe exposure for lead. The bottom line is, for young children and pregnant women, you want the lead exposure to be zero."

In Anna Wolfe's February 19, 2016, report of a Jackson City Council meeting as posted by the *Clarion-Ledger*, councilmen had questions about what officials were doing to address the high lead problems with residents' drinking water. Mayor Yarber noted that 70 % of Jackson homes were built before 1978 when lead plumbing was used in homes. Councilman Stamps moved to make an emergency declaration during the meeting but was unsuccessful. Stamps said, "I do see inaction, and as leaders we're here to take some action." Yarber responded, "I don't want to sound the wrong alarm (and have) folks saying 'We're Flint.' We're not Flint." Kishia Powell, Jackson's Public Works Director explained, "A major difference between Flint, Michigan, and Jackson, Mississippi, was that the crisis in Flint began because the city did not have corrosion control measure in place, whereas Jackson did."

In a Jackson City Council meeting at the Tougaloo College Chapel on March 22, 2016, Willie Bell, former interim Jackson Public Works Director, addressed problems in the city's water treatment plant. According to Anna Wolfe's report posted by the *Clarion-Ledger* at same day, Bell said, "With this water system, the real issue with our water is the pH holding consistency all the way through the system. Currently, the city utilizes lime powder to treat the water and to maintain pH and alkalinity levels. This could explain persistent clogging of the underground transportation pipes with the O. B. Curtis Water Treatment Plant. Because of this, the plant is currently using above-ground hoses to transport water within the plant. That's a problem."

When Bell was interim, he received an estimate of $400,000 for plant repairs, including a switch to a liquid lime treatment. Now the city leaders were discussing a $400,000 contract with an engineering firm to study problems with Jackson's water treatment system and recommend a solution. Bell stated: "The problem I have now, we are about to institute a study that costs $400,000, and we could take the $400,00, purchase the system and remedy the problem. Why are we going to pay him $400,000 to tell us something he already told us?" Bell also recommended that the city should be testing its own water to be sure residents were notified quickly if their water tested positive for lead.

Anna Wolfe reported in a March 24, 2016, post by the Clarion-Ledger, that Jackson resident Tracey Shanklin of the Heatherwood community purchased her own water testing kit and was appalled at the results. "Shanklin's water sample taken, from her kitchen sink after water was left dormant in the pipes for roughly eight hours, tested positive for 194.7 parts per billion of lead, nearly 13 times the federal action limit." Shanklin's response, "The take away—I'm using bottled water for everything." She had been using the water to make a pot of coffee every day. The article also reported that a Jackson official told 61-year-old Vernester Ingram on Witsell Road that water samples take at her home in February tested for 61.6 parts per billion of lead. Another Jackson home with high lead was a large white two story house on Newland Street that tested 476 parts per billion in January. A Jackson official blamed lead joints in the distribution system and recommended that testing for lead should be based on the age of the home.

On December 13, 2016, the Clarion-Ledger posted an article entitled, "A year later, Jackson's lead-water issue not solved." The article cited a home on St. Andrews Drive that tested 123 parts per billion of lead in August, more that eight times the federal limit. Another home on Floral Drive tested for 90 ppb of lead, and a sample from Colony Square for 86 ppb of lead. Residents were encouraged to flush their faucets before consuming the city's water, and pregnant women and children younger than 6 were not to drink the water.

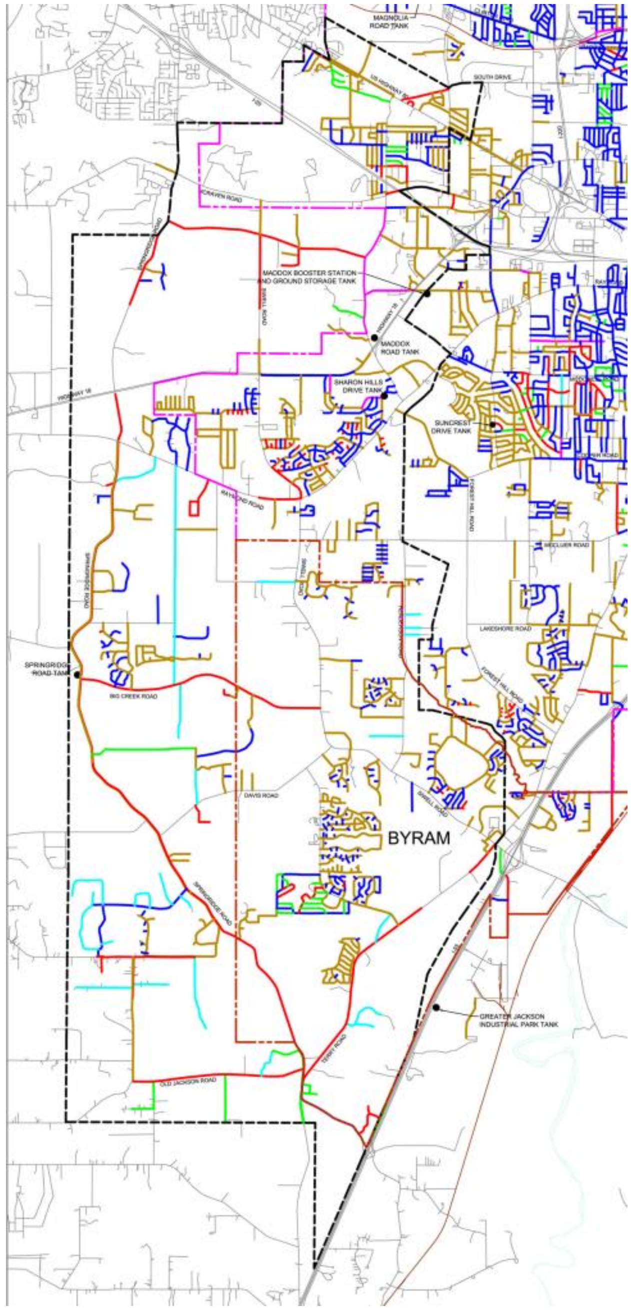


Figure 63. Maddox Road Well system in southwest Jackson outlined with a black border. Image 2533.

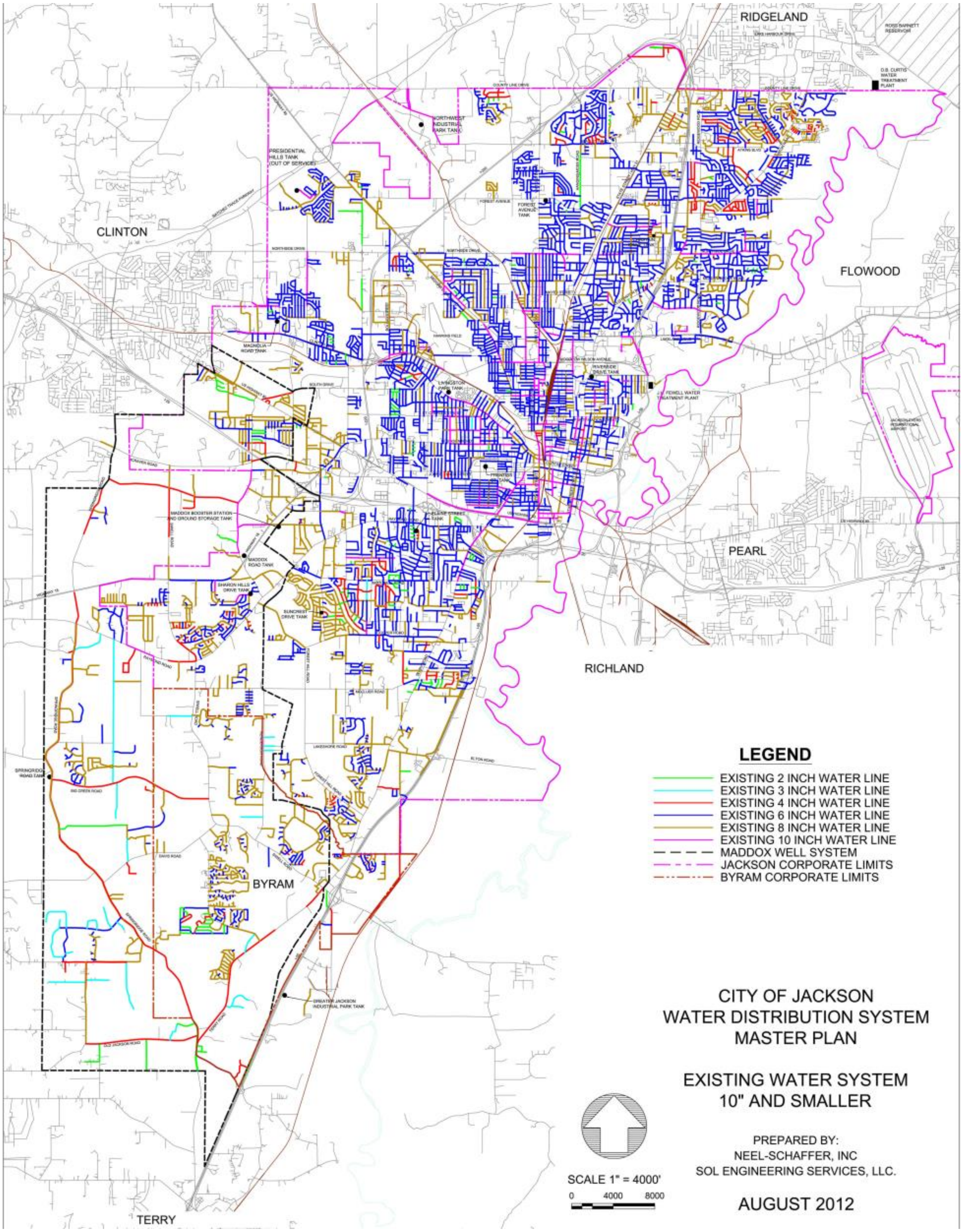


Figure 64. City of Jackson water distribution system master plan. Image 2634.

WATER WELL GEOPHYSICAL LOGS

The Mississippi Office of Geology (then the Mississippi Geological Survey) purchased its first "Wildco" logging unit on January 1, 1953 for the purpose of running geophysical logs on test holes associated with geologic mapping program. An early geophysical log produced by this unit in February of 1954 appears in the Panola County Geology Bulletin by Vestal (1956, fig. 20). The Wildco logger was used by John Marble as late as March 18, 1999 for the Jeff Burns water well in Clinton, Mississippi.

In 1964 the Office purchased a "Neltronic 3K" logging unit and initiated a full-scale logging program that provided free geophysical logs to water-well contractors. The new van-mounted logging unit had the capacity to log boreholes as deep as 3,300 feet and had natural gamma ray capabilities as well as recording spontaneous potential and resistivity electrical curves. Geophysical logs are the best means to aid water-well contractors in identifying fresh-water sands in which to set the screen for the well's water intake. They are also a valuable source of geologic data for the study of regional ground-water resources, for drafting geological cross sections, and for mapping surface geology. New logs are given a file number and stored in the Office of Geology's geophysical log file.

Today the Office of Geology uses modern technology with Mount Sopris digital logging units. **Figures 66-67** shows the logging of the Baptist Hospital #3 well in Jackson, Mississippi. Over the years the Office of Geology has logged wells between 30 and 2,400 feet deep in Alabama, Tennessee, Louisiana, and all 82 counties of Mississippi.. The Office currently has scanned records of geophysical logs and other data on 21,938 wells in Mississippi. Original hard copies of geophysical logs are kept in the Office of Geology water-well log file. These logs are arranged alphabetically by county and then by grid letter, beginning with the letter A in the northwestern most grid. **Figure 68** shows the grid map for the state of Mississippi. Grids in the system generally, but not entirely, follow township boundaries.

Figure 65. Logging cable extending from the drill hole and breakout table of the drilling rig to the logging van operated by the Mississippi Office of Geology. The drill hole is a test hole for the Baptist Hospital #3 water well in Jackson, Mississippi. Picture (digital; Image 1933) was taken on March 30, 2011.

Figure 66. John Marble monitors the digital logging unit, while logging the Baptist Hospital #3 well. In front of him is the cable drum, and to his right is the display screen showing the geophysical log. Picture (digital; Image 1934) was taken on March 30, 2011.

Figure 67. Computer display screen showing a portion of the Baptist Hospital #3 geophysical log as well logging is underway. Picture (digital; Image 1935) was taken on March 30, 2011.

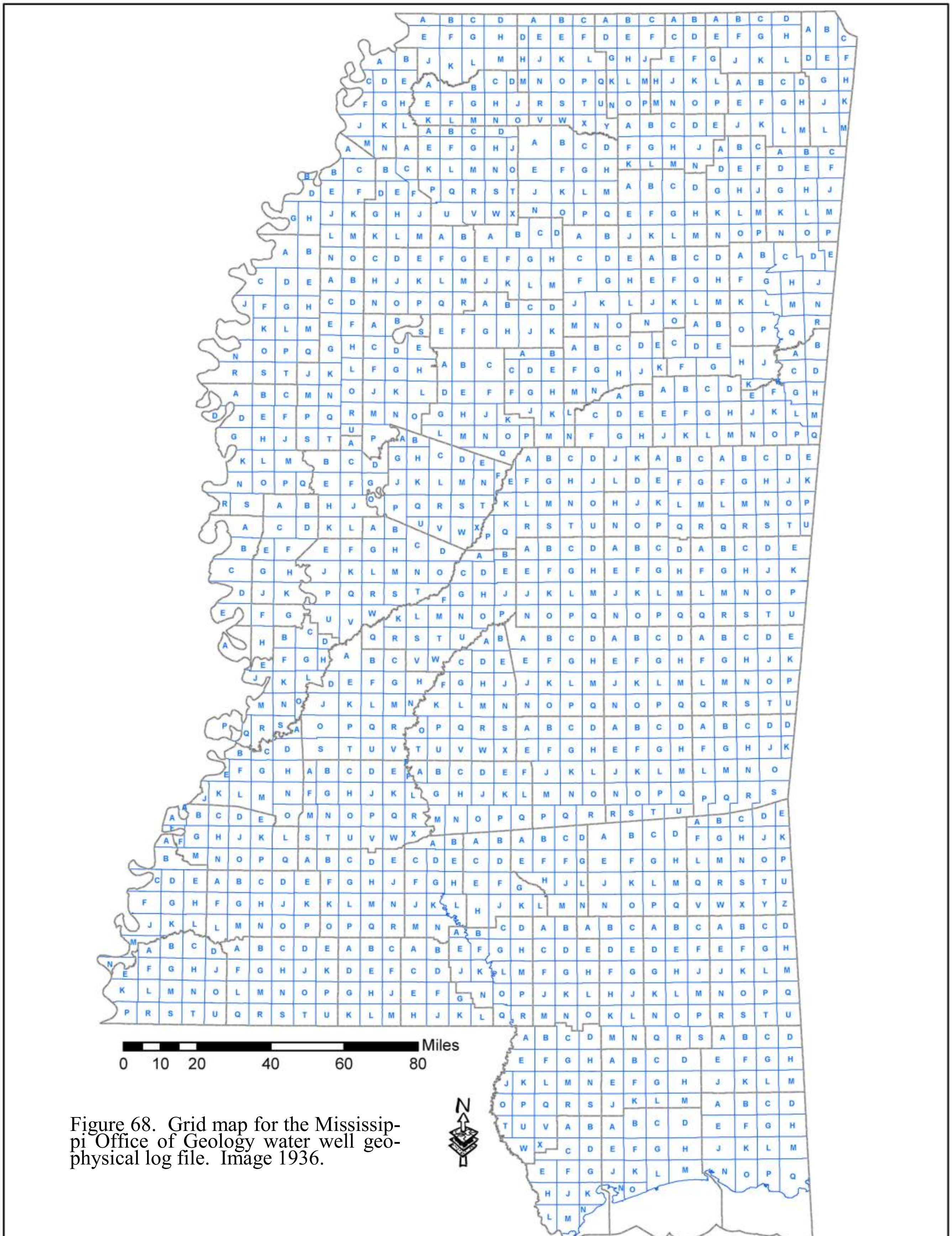


Figure 68. Grid map for the Mississippi Office of Geology water well geophysical log file. Image 1936.

CHAPTER 3. FLOODS AND LOW WATER

The Mississippi River. The present course of the Mississippi River is held in place by a system of artificial levees. Much of this levee system was prompted after a flood in 1927 reached a crest of 56.2 feet at Vicksburg, Mississippi, and flooded most of the Mississippi Delta region. After the 1927 flood, engineers determined that the headwaters of the Yazoo River caused much of the flooding that occurred in the Mississippi Delta. This led to the construction of four flood-control reservoirs, which, in order of construction, include (1) Sardis Lake on the Tallahtchie River completed in 1940, (2) Arkabutla Lake on the Coldwater River completed in 1943, (3) Enid Lake on the Yocona River completed in 1952, and (4) Grenada Lake on the Yalobusha River completed in 1954. **Figure 69** shows the construction of Sardis Lake and the unconformable contact of the Zilpha Clay and Koscuisko Formation. **Figures 70 and 71** show the topping of the Sardis emergency spillway by floodwaters associated with the Mississippi River flood of 1973.

Figure 69. Unconformable contact (X) of Kosciusko sand overlying Zilpha clay in the distant construction cut for Sardis Lake. Picture (scan of print, DVD 57; Image 1015) dated March 21, 1940.

In the 1940s, German prisoners of war were used to build a scale model of the Mississippi River at Clinton, Mississippi, to predict flood crests based on the water flow entering the Mississippi River Basin. This model was used in the flood of 1973, when it proved to better predict flood crest than the computer model used at that time (**Figures 72 and 73**). **Figure 74** shows the major historic flood crests depicted on the flood wall at Vicksburg, Mississippi. **Figure 75** shows the water mark (bathtub ring) left by the 2009 flood.

There have been three major floods on the Mississippi River in a period of just four years, including 2008, 2009, and 2011. The following is from the June 2011 issue of the Mississippi Department of Environmental Quality's newsletter Environmental News (pages 12-19) concerning these floods.

THE MISSISSIPPI RIVER FLOOD OF 2011

This article, in part, is from the June 2011 issue of *Environmental News* (Dockery, 2011, p. 12-19).

The April showers of 2011 brought not only May flowers, but higher than normal pollen counts, an increase in allergy sufferers, and

Figure 70. Sardis Lake tops its emergency spillway for the first time in the flood of March 1973. Picture (slide; Image 1787) was taken in March of 1973.

Figure 71. Overflow of the emergency spillway at Sardis Lake during the flood of March 1973. Picture (slide; Image 1788) was taken in March of 1973.

Figure 72. John Armentrout (front) photographing the Mississippi River hydraulic model at Clinton, Mississippi, the largest physical hydraulic model of its time. Picture (slide 153-4; Image 521) was taken on March 28, 1985.

Figure 73. Mississippi River hydraulic model at Clinton, Mississippi; built by German prisoners of war in the 1940s, it was last used to accurately predict flood crests during the 1973 Mississippi River flood when computer models were found to be inadequate. It has been allowed to deteriorate since this picture was taken. Picture (slide 153-5; Image 522) was taken on March 28, 1985, during an AAPG field trip.

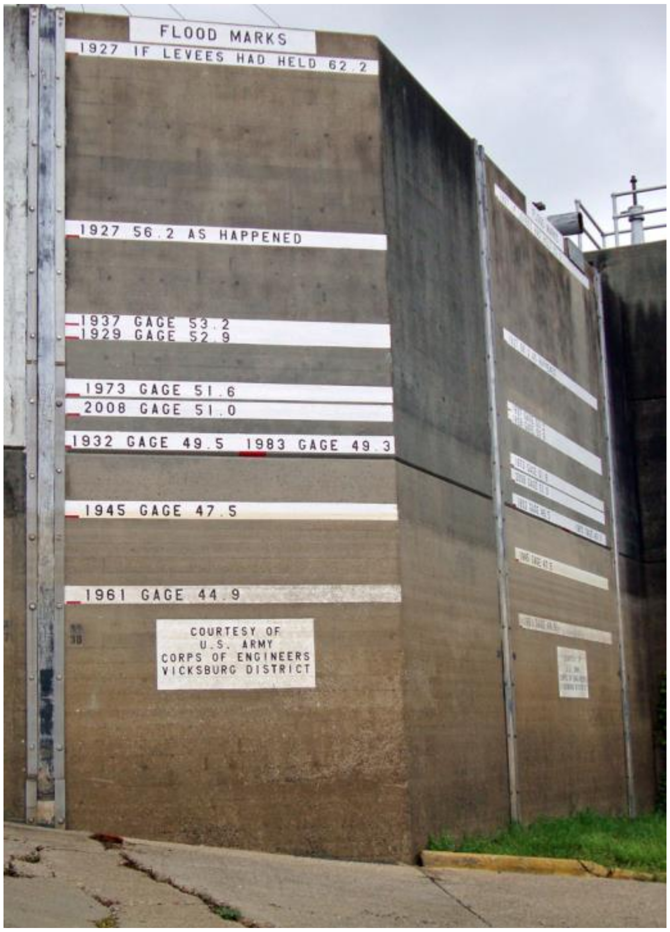


Figure 74. Vicksburg flood wall with historical flood crests marked by the U.S. Army Corps of Engineers. The water lines (bathtub rings) for the 2008 and 2009 floods can be seen to the right of the facing wall. Picture (digital; Image 1801) was taken on September 26, 2009.

"a rising tide" down the Mississippi River. Heavy April rainfall accumulations in the Ohio River Valley and melting snow packs in the upper Mississippi River Valley have produced record flood crests on the Mississippi River in what has been called "The Great Flood of 2011." MDEQ personnel have put a tremendous effort into flood response, with: (1) continuous activity in every river county from DeSoto to Wilkinson County, (2) many meetings with city and county officials and with state and federal officials, (3) presence in the state Emergency Operations Center, (4) contributions and coordination of GIS data, (5) planning and preparations for debris handling and disposal, (6) status of wastewater treatment facilities, (7) removal of hazardous materials, (8) response to oil spills, and (9) the daily issuance of situation reports on MDEQ flood-related activities.

On the May 12 edition of NBC Evening News, Brian Williams stated, "This flooding is a disaster, some of it historic, epic proportions, but something else is also true. It was predicted. We knew it was coming." He then gave this year's record snowfall accumulations for certain northern cities (see "Mississippi Winter Weather Emergencies, 2011" in the March 2011 edition of *Environmental News*). Oddly enough, the flood crest arrived in Mississippi during some of the coldest mid-May temperatures on record, with a record low day-time high in Jackson of 62 degrees F on May 16 and low the following morning of 42 degrees F. Mid-May was both cold and dry, which was fortunate in two ways: (1) rainfall did not add to the flood crest, and (2) the dry Delta soil soaked up enough water to significantly diminish the predicted flood crest. Another factor that lowered the flood crest in Mississippi was a breach in the 18-mile-long Bunches Bend farm levee in East Carroll Parish, Louisiana, across the river from Rolling Fork, Mississippi. The breach occurred on May 13, 2011, flooded 10,000 acres of prime Louisiana farmland, and dropped the river level half a foot at Greenville, Mississippi, before the river continued its rise. Due to the dry weather and breached levee, the predicted overtopping of the Yazoo Backwater Levee by one foot of flood water never happened.

The Great Flood of 2011 was unique, not only in its magnitude, but also because it was the third Mississippi River flood in just four years. Back to back flood years in 2008 and 2009 had flood crests at Vicksburg, respectively, of 51.0 feet and 47.5 feet. The 2008 flood was the highest flood since the 51.6

Figure 75. Ida Marshall pointing to the "bathtub ring" above the flood crest of the 2009 Mississippi River flood on the Vicksburg flood wall. Picture (digital; Image 1802) was taken on September 26, 2009.

Figure 76. The 2008 Mississippi River flood crest as seen at the Vicksburg flood gate and on the flood wall, just below the 1973 level. Pictures (digital; Images 1790 and 1791) were taken on April 20, 2008.

Figure 77. Vicksburg flood gate (left) and flood wall (right) at the crest of the 2009 flood, which rose to the level of the 1945 flood crest. Pictures (digital; Images 1795 and 1796) were taken on May 26, 2009.

-foot flood crest of 1973, some 35 years earlier. The U.S. Army Corps of Engineers placed the 2008 crest level on the Vicksburg flood wall with those of other historic crests (**Figure 76**). **Figure 77** shows the water mark of the 2009 flood crest on the floodwall at Vicksburg.

Figure 76 shows the planked up flood gate in 2008, and a photograph of the crest against the flood wall as taken from the flood gate. The flood of 2009 did not require the closure of the flood gate, but, as seen on the flood wall, it rose to the level of an historic flood in 1945 (**Figure 77**). In both the 2008 and 2009 floods, Highway 465 was closed just west of Highway 61 due to flooding, which turned the farmland of the lower Yazoo River Basin into a large lake (**Figure 78**).

The flood gates at Vicksburg were planked all the way to the top in preparation for the Great Flood of 2011. This planked closure had to be extended along the north end of the flood wall (**Figure 79**). Photographing the rising crest on the flood wall in 2011 (**figures 80-81**) required a 24-foot extension ladder and Homeland Security clearance from Vicksburg Emergency Management Director Anna Booth and notification of Lieutenant Davey Barnett of the Vicksburg Police Department. The Great Flood of 2011 not only covered Highway 465 (**Figure 82**) but also sections of Highway 61 (**Figure 83**) and many homes and businesses (**Figure 84**). With a crest of 57.1 feet

Figure 78. Highway 465 just west of Highway 61 during the 2008 (left) and 2009 (right) flood crests. Picture on left (digital; Images 1792) was taken on April 20, 2008; picture on right (digital; Image 1797) was taken on May 26, 2009.

Figure 79. Planking up and tarring the north end of the Vicksburg flood wall. Picture (digital; Image 1879) was taken on May 6, 2011.

Figure 80. At left, David Dockery takes a picture northward along the Vicksburg flood wall (as seen in Figure 81). At right, WLBT's Skycopter 3 films the flood crest along the flood wall. Pictures (digital; Composite image 1872) were taken by Mary Dockery on May 19, 2011.

Figure 81. The Mississippi River flood crest of 2011 on the flood wall at Vicksburg. Picture (digital; Composite image 1873) was taken on May 9, 2011.

on the evening of May 18, it it now the highest flood level ever recorded at Vicksburg (**Figure 85**)

The Great Flood of 2011 continured its record breaking crests downstream with a crest of 61.8 feet, or 13.8 feet above flood stage, at the City of Natchez on May 21, a level significantly below the predicted crest of 64 feet. The previous record at Natchez was 58.04 feet set on February 21, 1937. **Figures 86 and 87** compare Natchez under the Hill during the flood crests of April 21, 2008, at 57.03 feet, and May 21, 2011, at 61.8 feet. On April 21, 2008, backwater flooding north of Natchez in the Port Gibson area was so high that Highway 61 was flooded just north of the Big Black River bridge and fields on both sides of the Natchez Trace Parkway were flooded just south of the Little Bayou Pierre bridge (**Figure 88**).

On May 9, 2011, the Mississippi River discharge at Vicksburg, Mississippi, exceeded two million cubic feet per second and rose to a maximum flow of over 2,330,000 feet per second on May 18 and 19, 2011. The following are some interesting flood statistics provided by Jared Wright of the U.S. Geological Survey (Pearl, Mississippi) based on USGS measurements:

Figure 82. 2011 flood waters have submerged all but a small peninsula of Highway 465 and threaten to cover Highway 61. Pictures (digital; Composite image 1874) were taken on May 11, 2011.

Figure 83. Flood waters submerge Highway 61 in Vicksburg. Picture (digital; Image 1880) was taken on May 16, 2011.

The Mississippi River at Vicksburg, on May 19, 2011, had a total discharge of 2,321,000 cubic feet per second, a maximum depth of 185 feet, a maximum velocity of 18.1 feet per second, and an average velocity of 8.82 feet per second.

The Mississippi River at Natchez, on May 20, 2011, had a total discharge of 2,260,000 cubic feet per second, a maximum depth of 129 feet, a maximum velocity of 18.9 feet per second, and an average velocity of 9.31 feet per second. On May 21, it had a total

84. Flood waters of the Mississippi and Yazoo rivers merge at their confluence and extend their shores to the bluff line at Vicksburg, leaving a jacked-up office building surrounded by the swift currents of the Mississippi River (behind) and the backwaters of the Yazoo River (in front). Picture (digital; Image 1881) was taken on May 16, 2011.

discharge of 2,170,000 cubic feet per second, a maximum depth of 136 feet, a maximum velocity of 18.3 feet per second, and an average velocity of 8.76 feet per second.

The Mississippi River ranks seventh among the world's rivers in average discharge, with an average discharge of 611,000 cubic feet per second. The largest river in this ranking is the Amazon River with an average discharge of 7,500,000 cubic feet per second; second is the Congo River with an average discharge of 1,400,000 cubic feet per second. During the Great Flood of 2011, the Mississippi River's discharge of over two million cubic feet per second placed it, for a time, as second among the world's rivers. Another interesting fact of this flood was the rate of backwater flooding on the Yazoo River, which produced a negative flow rate at Redwood on May 12 of 46,000 cubic feet per second. The flow rate on the Pearl River at flood stage in Jackson is only 20,000 cubic feet per second. So, the Yazoo River's backward discharge was more than twice the Pearl River's forward discharge at flood stage.

The 2011 Mississippi River Flood and Hazardous Materials

The 2011 Mississippi River flood inundated residential and commercial areas where hazardous material were stored above ground and in underground tanks. It also flooded oil fields in Adams County, Mississippi. Here the flood covered well heads and pumps, pipe-

Figure 85. The rising tide of the Great Flood of 2011, climbing the Vicksburg flood wall. From left to right, pictures were taken around noon on: (1) May 9 below the 1929 flood crest of 52.9 feet, (2) May 11 below the highest recorded flood crest in 1927 of 56.2 feet, (3) May 16 above the 1927 flood crest, and (4) May 19 at a record crest of 57.1 feet. The bolt above and left of the 1927 mark was at water level on May 16 (3) and below water level on May 19 (4). Picture (digital; Composite image 1875).

Figure 86. Left, flood crest at Natchez Under the Hill on April 21, 2008, water is at the base of the lower gate post; the upper gate post at the curb is high and dry. Right, flood crest at Natchez Under the Hill on May 21, 2011, water is at the base of the upper gate post; the lower gate is covered except for the top of the gate post . Picture (digital; Composite image 1876).

Figure 87. Left, flooded street at the Isle of Capri landing in Natchez Under the Hill on the April 21, 2008, flood crest. Right, make-shift levee built around the Isle of Capri low spot and against the river, as seen on the May 21, 2011, flood crest; businesses inside the levee remained open. Picture (digital; Composite image 1882).

Figure 88. Left, backwater flooding on Highway 61 in Warren County just north of the Big Black River bridge. Right, backwater flooding on the Natchez Trace Parkway just south of the Bayou Pierre River bridge. Picture on left was taken on May 18, 2011, by James Matheny; picture on right was taken on May 21, 2011, by David Dockery. Picture (digital; Composite image 1883).

lines, and oil storage tanks. **Figures 79-82** were taken by James Matheny who represented the Mississippi Department of Environmental Quality in a survey of the condition of flooded oil field equipment. **Figure 89** shows the top of an oil well pump above flood waters below Learned Bluff at Natchez, Mississippi. **Figures 90-92** illustrates the work in placing bags of cement on top of Biglane Operating's oil storage tanks to keep the tanks from floating away in the river currents.

The Bunches Bend Levee Failure in the 2011 Mississippi River Flood

Figure 93 shows the capacity of the Mississippi River and its levee systems from St. Louis to the Gulf of Mexico, according to the Mississippi River Commission's 2008 Project Design Flood. The capacity of this model flood is 2,890,000 cubic feet per second at

Figure 89. A flooded oil-well pump below Learned Hill at Natchez, Mississippi. Picture (digital; Image 1886) was taken by James Matheny on May 20, 2011.

Figure 90. Flooded oil storage tanks for Biglane Operating wells below Learned Bluff at Natchez, Mississippi. Picture (digital; Image 1887) was taken by James Matheny on May 20, 2011.

Figure 91. A jon boat carries bags of cement to weight down the tops of Bigland Operating's oil storage tanks below Learned Bluff at Natchez, Mississippi, in an effort to protect them from barge wakes, which might release oil by loosening pipe fittings. Picture (digital; Image 1888) was taken by James Matheny on May 20, 2011.

Figure 92. Placing bags of cement on Biglane Operating's flooded oil storage tanks below Learned Bluff at Natchez, Mississippi. Picture (digital; Image 1889) was taken by James Matheny on May 20, 2011.

Greenwood, Mississippi. As the flood crest approached Greenwood in the 2011 Mississippi River flood, there was a failure in the levee system on the Louisiana side across the River from Rolling Fork, Mississippi.

On May 13, a secondary farm levee failed at Bunches Bend in East Carroll Parish, flooding 10,000 acres of prime Louisiana farmland (**Figure 94**), wiping out $10 million in crop revenue, and excavating an 80-foot-deep hole in farmland at the breach site. A U.S. Army Corps of Engineers official was quoted as saying that when the levee failed, the Mississippi River level temporarily dropped a half-foot at Greenville, Mississippi (**Figure 95**). This was the first breach of the levee since its construction by the Corps in 1912. Failure of the Bunches Bend levee lowered the flood crest at Vicksburg enough to prevent the overtopping of the Yazoo Backwater Levee and the flooding of additional farmland in Mississippi (**Figure 96**).

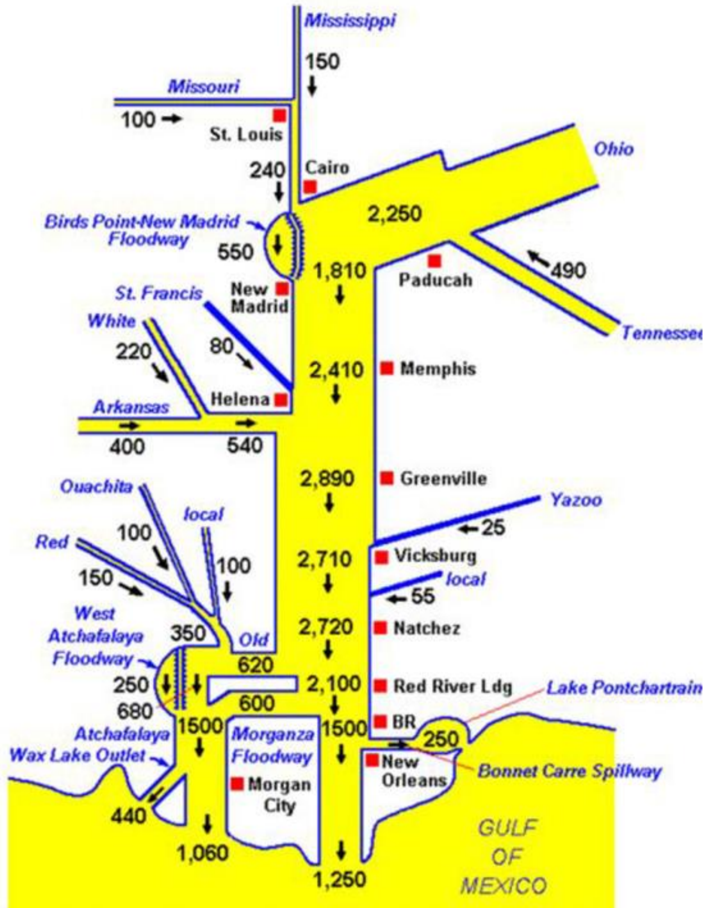


Figure 93. Flow capacity for the Mississippi River from St. Louis to the Gulf of Mexico in thousands of cubic feet per second according to the Project Design Flood of the Mississippi River Commission, 2008. Image 1894.

Figure 94. Left, failure of a secondary levee protecting 10,000 acres of farmland at Bunches Bend in East Carroll Parish, Louisiana, on May 13, 2011. A U.S. Army Corps of Engineers official was quoted as saying that when the levee failed, the Mississippi River level temporarily fell a half-foot at Greenville, Mississippi. This is the first breach of the levee since its construction by the Corps in 1912. Photograph from News-Star file photo. Image 1895.

Figure 95. Mississippi River flood crest recorded on the gage at Greenville, Mississippi (graph from Jared Wright, USGS). The flood level dropped half a foot at Greenville on May 14 after the failure of the Bunches Bend farm levee on May 13, 2011. Image 1896.

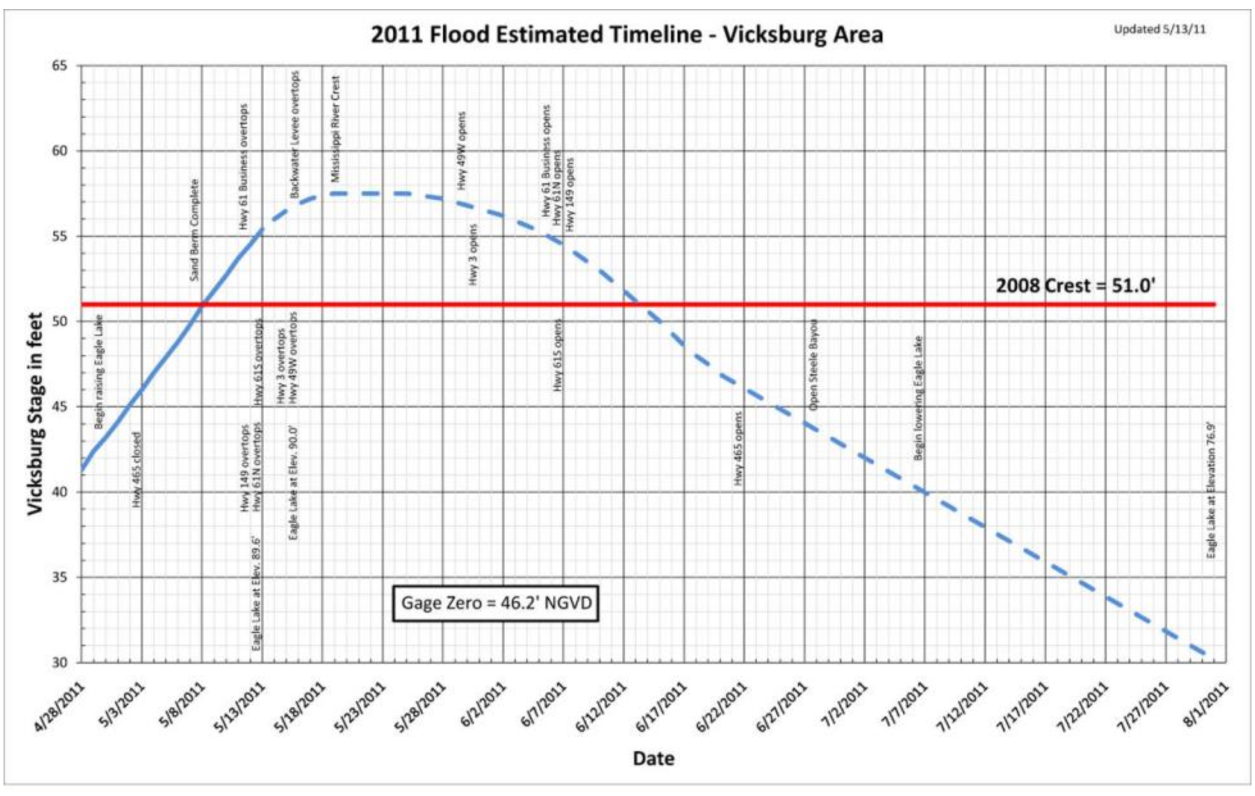


Figure 96. 2011 estimated flood timeline of the Vicksburg area as of May 13, 2011. The estimated time for the overtopping of the Yazoo Backwater Levee was May 16, when the flood level would be around 57 feet and before the predicted crest of 57.5 feet. Due to the Bunches Bend Levee breach, the flood crest was only 57.1 feet. Image 1897.

THE PEARL RIVER EASTER FLOOD OF 1979

On January 17, 1979, after heavy rains, the Pearl River at Jackson rose to a near record flood crest of 35.80, about 18 feet above flood stage (which is 18.0 feet at the Highway 80 gage at Jackson). The river level dropped to 7.9 feet by April 2 but rose again after heavy rains to 28 feet on April 11. So, the river level was high when a new storm system struck the area.

April 10, 1979, a warm front moving east across the plains states spawned tornados, one of which struck Wichita Falls, Texas, around 6:00 p.m., causing 400 million in damages and taking 42 lives. Many were killed when they tried to flee the storm in their cars as the tornado moved along U.S. Highways 281 and 287. This was the big item on national news as the same weather front moved into western Mississippi as a cold front on Wednesday afternoon (April 11), causing heavy thunderstorms in the western part of the state. During the next 36 hours, these storms formed repeatedly over much of central Mississippi from Jackson to Columbus. When the rain stopped on Good Friday morning of April 13, a total accumulation of 8 inches covered the upper Pearl River Basin with nearly 20 inches at Louisville. In east-central Mississippi, 15 to 20 inches of rain fell in Choctaw, Winston, and Oktibbeha counties. Jackson received 10 inches of rain, including 4 inches that fell in just one hour on Thursday, April 12. Flood waters covered a section of the Natchez Trace Parkway south of Kosciusko on Friday, and by Saturday the Natchez Trace was closed north of Jackson due to flooding, where flood waters reached a surface elevation of 313.10 feet above sea level at Ratliff's Ferry.

Thursday morning on April 12, river forecasts called for crests near record levels on the upper Pearl River and at Jackson for Friday and Saturday. The previous record flood of 37.5 feet occurred in 1902, and a modern day record of 37.2 feet occurred in 1961, just after completion of the Ross Barnett Reservoir. On the morning of Good Friday, April 13, after storms associated with the weather front ceased, the river was at 33.5 feet at Jackson and rising rapidly under the blue skies of a beautiful day. At 11:10 a.m. on Friday the Na-

Figure 97. Maximum outflow from the Ross Barnett Reservoir spillway of 130,000 cubic feet per second, after fears that the dam might be topped by the Pearl River Eastern flood of 1979. Picture (scanned print 414-1; Image 1898) was taken on April 15, 1979.

Figure 98. Concrete skirt that directs Ross Barnett Reservoir waters into the spillway on the spillway's west side. The mud level on the white gage shows the water level to have risen within 1.6 feet of the top of the skirt before the opening of the spillway to maximum outflow. Picture (scanned print 414-2; Image 1899) was taken on April 15, 1979.

Figure 99. People fish in the rising flood waters of the Pearl River below the Ross Barnett Reservoir dam. Picture (scanned print 414-3; Image 1900) was taken on April 15, 1979.

Figure 100. Back water flooding from Hanging Moss Creek covers Ridgewood Road in northeast Jackson. Picture (scanned print 414-4; Image 1901) was taken on April 15, 1979.

Figure 101. Back water flooding from Hanging Moss Creek covers the Kroger parking lot along the frontage road on Interstate 55 North in northeast Jackson, as a driver has his car towed from the rising water. Picture (scanned negative 416-32C; Image 1902) was taken on April 15, 1979.

Figure 102. Back water flooding from Hanging Moss Creek covers Canton Mart Road as viewed to the east toward Old Canton Road in northeast Jackson, as a John boat carries belongings from flooded stores to a waiting truck. Picture (scanned negative 416-34C; Image 1903) was taken on April 15, 1979.

Figure 103. Back water flooding from Town Creek covers a gas station on South State Street in south Jackson. Picture (scanned negative 416-17C; Image 1904) was taken on April 15, 1979.

tional Weather Service at Jackson called for a record flood crest of 37.5 feet by Saturday, with indications that it could go higher. By 5:00 a.m. Saturday morning, the river reached 37.6 feet at Jackson, surpassing the old record, and continued rising at an alarming rate. At 10:00 p.m. Saturday, the river was projected to rise to a crest of 41.5 feet on Sunday.

On the Rankin County side of the river, hundreds to thousands of volunteers worked day and night to reinforce the Rankin levee, raising its height by 3 feet. Nothing was done to the levee on Jackson's side of the river, while residents of Jackson were advised by city officials not to panic. When the flood water did come, it was too late for many. Some residents prepared for the flood by renting moving trucks, which were kept parked in their driveways full of furniture and household items, waiting for the call to evacuate. The flood overtook the streets and flooded homes and moving vans in place.

Easter Sunday at 5:00 a.m, the river reached 41 feet and was predicted to rise to 42 feet Sunday afternoon. Panic gripped some residents when helicopters flew over areas at 3:00 a.m. Sunday, calling for people to evacuate. Also on Sunday, inflows into the reservoir exceeded outflows; the latter were hastily increased. The Jackson flood was underway.

Figure 104. Back water flooding from Town Creek floods Pearl Street in downtown Jackson, as sandbags are filled to protect downtown buildings. Picture (scanned negative 416-22C; Image 1905) was taken on April 15, 1979.

Figure 105. Back water flooding on Pearl Street in downtown Jackson as seen from a distance on Sunday, two days before the flood crest on Tuesday. Picture (scanned negative 413-21C; Image 1906) was taken on April 15, 1979.

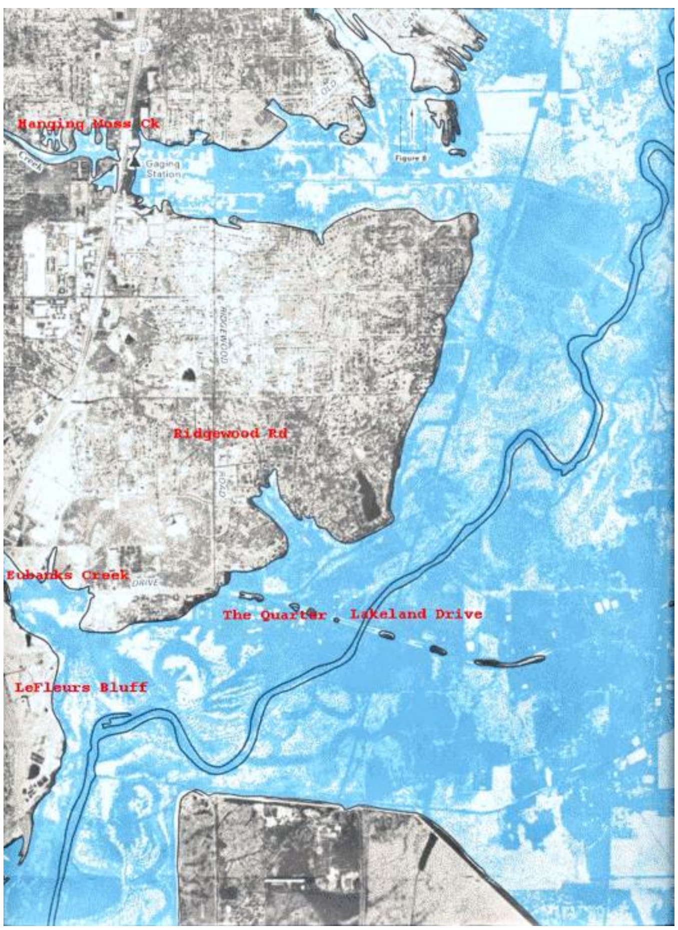


Figure 106. Flood inundation along Hanging Moss Creek at upper left at the flood crest of the Easter 1979 Pearl River flood in north Jackson. Image 1907; from the National Weather Service Weather Forecast Office, Jackson, Mississippi..

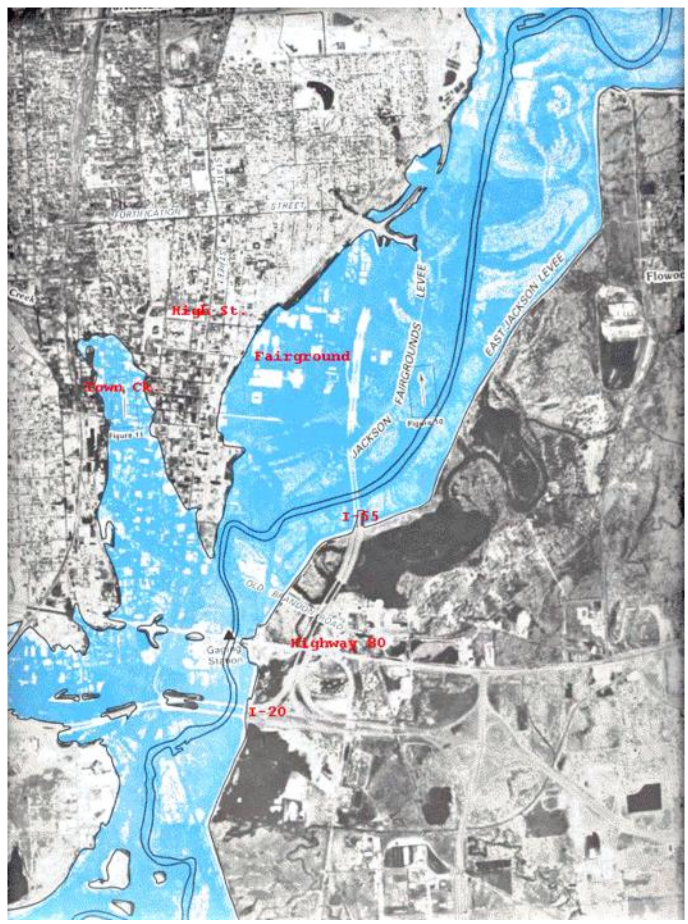


Figure 107. Flood inundation along Town Creek at middle left at the flood crest of the Easter 1979 Pearl River flood in south Jackson. Image 1908, from the National Weather Service Weather Forecast Office, Jackson, Mississippi.

Figure 108. Flood debris accumulates against a railroad bridge over the Pearl River in south Jackson. The bridge is submerged in the distance. Tires with wheels on the bridge are being salvaged. Picture (scanned negative 416 -11C; Image 1909) was taken on April 15, 1979.

Figure 109. Dangerous boat ride in a jon boat against strong currents and with low clearance under the Woodrow Wilson Bridge over the Pearl River in south Jackson. The bridge is submerged in the distance. Picture (scanned negative 416-20C; Image 1910) was taken on April 15, 1979.

Figure 110. Cars and trucks moved from flooded areas and parked at the Mississippi Memorial Stadium in Jackson. Picture (scanned negative 415-1C; Image 1911) was taken on April 17, 1979.

Figure 111. David Dockery Jr. walking the south end of the Jackson levee as flood waters near the levee's top. After a modest walk, my father (Jr.) and I worried that we might be trapped should be levee be overtopped behind us. Picture (scanned negative 416-C; Image 1912) was taken on April 15, 1979.

Communications concerning flood crest prediction broke down as accounted by the National Weather Service as follows:

"Meanwhile, communications were breaking down. Water had closed a number of Mississippi Power and Light (now Entergy) substations, and power outages were threatened. Phones were either jammed or out completely. We could no longer get to the gage since apparently half of Jackson now had the number to it. It was increasingly difficult to talk with reservoir officials. Eventually their phones failed. The Jackson-Hinds Emergency Operations Center had been flooded out and had moved to cramped, unfamiliar quarters in the police communications center, where they had no weather wire or NAWAS, and all phone numbers were different. We were nearly isolated as far as communications were concerned."

On Saturday, flood waters raised the lake level of the upper reservoir to a point that shoreline homes were flooded. There was concern that the flood crest might top the reservoir dam; all spillway gates were opened to their maximum discharge of up to 130,000 cubic feet per second (**figures 97– 98**), as compared to the normal rate of 9,200 cubic feet per second. Trailer homes below the spillway were soon flooded. As residents were trying to save their belongings, people lined the spillway side of the dam to fish (**Figure 99**). Flood water then moved up tributaries to flood subdivisions in northeast Jackson, including the expensive

Figure 112. Flood waters pour across the north end of the Jackson levee and cascade south down Interstate 55 at Fortification Street Exit 31. Picture (scanned negative 416-24C; Image 1913) was taken on April 15, 1979. Picture continues to the right in Figure 85.

Figure 114. Placid floodwaters, which overtopped the north end of the Jackson levee, break into rapids over the Interstate 55 Exit 31 ramp at Fortification Street before flowing south down the interstate. Picture (scanned negative 415-6C; Image 1915) was taken on April 17, 1979, the day of the flood crest.

homes in Eastover. Back flooding on Hanging Moss Creek covered sections of Ridgewood Road (**Figure 100**), and the Kroger parking lot along the Interstate 55 frontage road (**Figure 101**) and nearby Canton Mart Road (**Figure 102**). In South Jackson, flood waters moved up Town Creek to flood South State Street and the downtown area (**figures 103-105**, **107**). **Figure 108** shows flood debris trapped against the Illinois Central Gulf Railroad bridge over the Pearl River in South Jackson, and **Figure 109** is a picture of a John boat passing under the partially flooded Woodrow Wilson Bridge. Many state and city vehicles were moved from flooded areas to high ground at the Jackson stadium parking lot (**Figure 110**).

Figure 113. Flood waters overtop the north end of the Jackson levee at the Interstate 55 Exit 31 ramp at Fortification Street. Highway Department personnel and others watch helplessly as a late effort to sandbag the levee was unsuccessful. Water flowing down the interstate crashes against the interstate right-of-way fence. Picture (scanned negative 416-25C; Image 1914) was taken on April 15, 1979.

Figure 115. Flood waters overtopping the north end of the Jackson levee flow south like a river down Interstate 55 into the State Fairgrounds area. Picture (scanned negative 415-9C; Image 1916) was taken on April 17, 1979, the day of the flood crest.

The State Fairgrounds area, which was protected by the Jackson levee, experienced backwater flooding through manholes of a 66-inch sewer line built only four years earlier in 1975. This line carried sewage from north Jackson to the sewage treatment plant in Byram. To do so, it penetrated the Jackson levee and crossed the flood waters of Town Creek. On Sunday, April 16, flood water was near the top of the Jackson levee (**Figure 111**). Before topping the levee, the water found the lowest point on the levee's north end and overflowed the Interstate 55 Exit 31 ramp at Fortification Street, flowing down the interstate as if it were a river (**figures 112-116**).

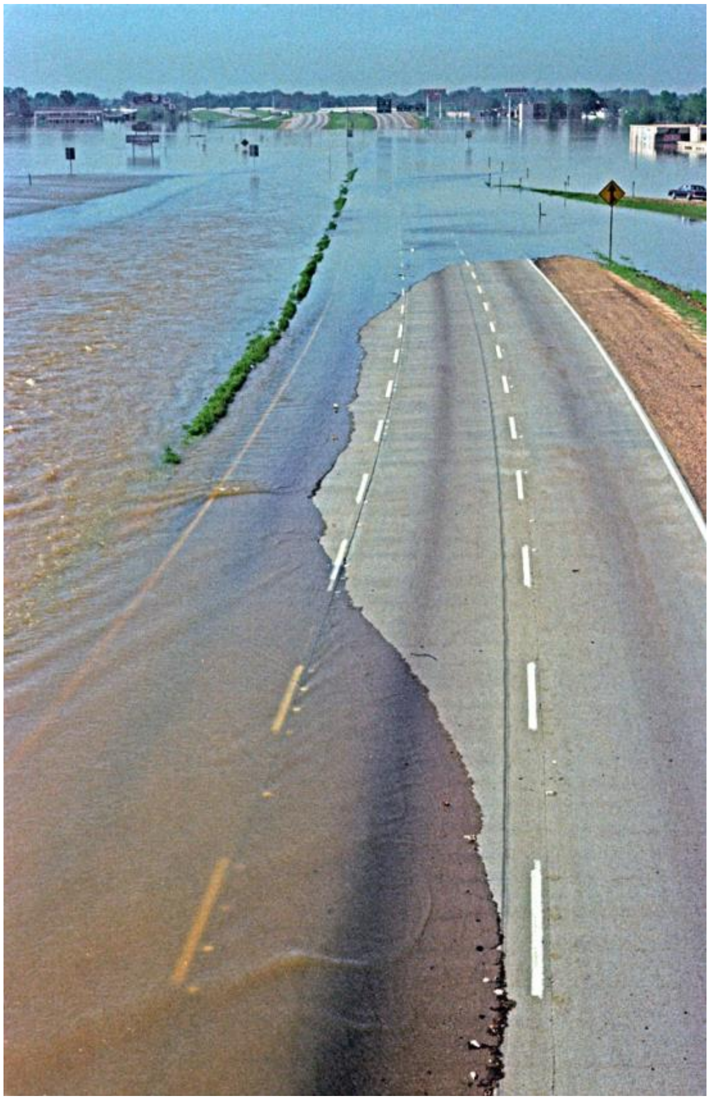


Figure 116. Flood waters flowing south down Interstate 55 into the State Fairgrounds area. In the distance, the interstate rises above the flood waters at the High Street interchange. Picture (scanned negative 415-26C; Image 1917) was taken on April 17, 1979, the day of the flood crest.

Flood waters inundated and shut down three of the city's power substations. Two others, including one on Jefferson Street that powered the downtown area, were saved by improvised levees. Flood waters also overwhelmed the city's sewage treatment plant, mixing raw sewage with river water, and threatened to cut off the city's public water supply by flooding the Jackson Waterworks. To save the Waterworks, a makeshift levee was built around the facility (**Figure 114**). Still, the system's intake pumps were flooded and inoperable. To replace them, tractors powering mechanical pumps and diesel water pumps were used to pump river water into the waterworks (**Figures 118-120**).

Figure 117. An improvised levee hurriedly built around Jackson's Water Treatment Plant strands a railcar inside the levee. Picture (scanned negative 415-33C; Image 1918) was taken on April 15, 1979.

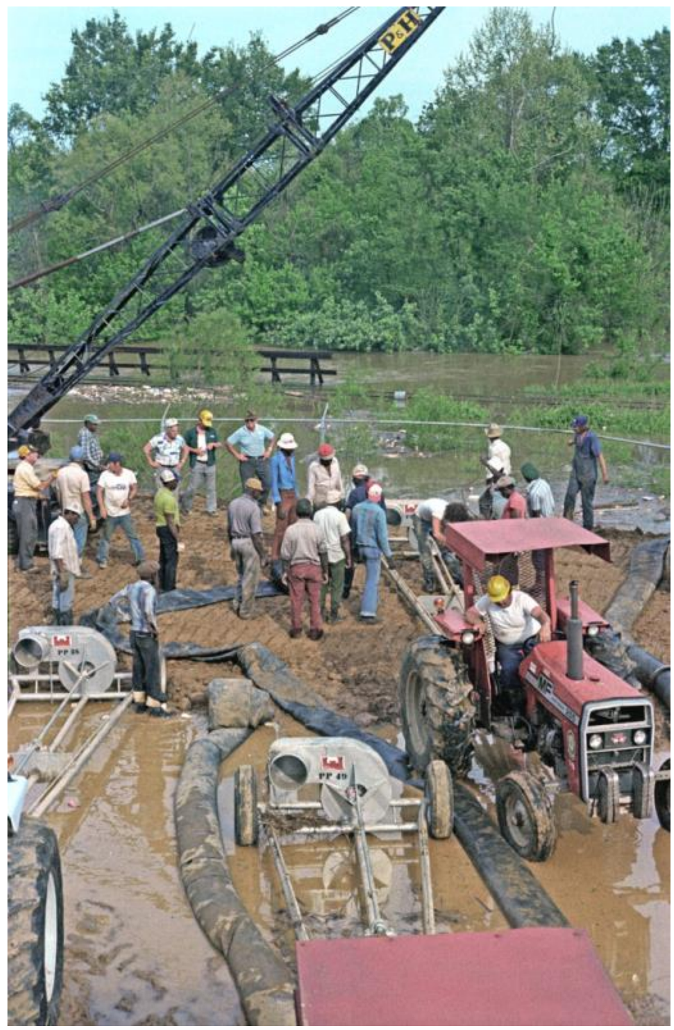


Figure 118. At right, tractors power mechanical pumps to supply river water to the Jackson Water Works Plant. Picture (scanned negative 415-35C; Image 1919) was taken on April 15, 1979.

Figure 119. Pumping temporarily ceases as more dirt is added to raise the levee around the Jackson Water Works Plant. A limp rubber hose tied to the top of the Water Works wall can be seen at left draped around the metal pipe. In the background is a flooded railroad bridge. Picture (scanned negative 415-34C; Image 1920) was taken on April 15, 1979.

Figure 120. Diesel pumps are added to the mix of tractor-powered pumps to supply the Jackson Water Works with a steady flow of river water. Picture (scanned negative 415-36C; Image 1921) was taken on April 15, 1979.

Figure 121. Flooded downtown Jackson at the flood crest of the Pearl River on April 17, 1979, looking north-east. Image 1922, from the National Weather Service, Jackson, Mississippi.

Figure 122. Flooded downtown Jackson at the flood crest of the Pearl River on April 17, 1979, looking southeast. Image 1928, from the National Weather Service, Jackson, Mississippi.

Flood waters of the Pearl River reached a record crest at Jackson of 43.25 feet around 3:00 p.m. Tuesday afternoon, April 17 (**Figures 121-122**). About 20 % of Jackson's land area was flooded, some of it for as much as a week. Seventeen thousand people were evacuated from some 2,000 homes. Damage estimates to public and private property were around $500 million (in 1979 dollars). **Figures 121** and **122** are from the National Weather Service, Jackson, Mississippi, and show the flooded downtown area and State Fairgrounds at the flood's crest.

THE DROUGHTS OF 2012, 1988, 1980-1982, AND 1956 AND LOW WATER ON THE MISSISSIPPI RIVER

This article, in part, is from the August 2012 issue of *Environmental News* (Dockery, 2012, p. 12-19).

The Midwestern drought of 2012 is the worst drought in 50 years, since the drought of 1956. It has created a reduction in corn and soybean supplies and a low flow on the Mississippi River that rivals that of the drought of 1988. The record of past droughts is "remembered" by trees and is preserved in the thicknesses of tree rings. Dendrochronology is the scientific method of dating wood by the analysis of tree-ring patterns. The study of dendrochronology has applications in: (1) climate and paleoecology, (2) in archaeology in dating old buildings, and (3) as a calibration for radiocarbon dating. When a large red oak fell next to my house (but missed) after a rain event on March 22, 2012, I thought it might contain a tree-ring record extending back some 100 to 150 years. To my surprise, the tree was only a little older than I was. Even so, it was old enough to record drought years back to the drought of 1956. Oaks are a good source of tree-ring information because annual rings are rarely missed in oak and elm trees. The only known instance of a missing ring in oaks is for the year 1816, which is known as the "Year without a summer." This event followed the eruption of Mount Tambora in Indonesia in 1815, the largest known eruption in over 1,300 years.

Figure 123 shows the process of cutting up the fallen tree and a cross section of the trunk with rings labeled by decades from 1950 to 2010. The drought years of 1956 and 1988 are also labeled. The last decade of tree growth was slower with smaller rings probably due to an area of growing rot at the base of the tree. The 1988 ring stands out as much smaller that the rings before or after. Drought years of 1980-1982 affected the northern part of the state and are not recorded in this tree's rings. Even so, the effect of the 1980-1982 drought

Figure 123. Red oak tree in northwestern Hinds County that fell on March 22, 2012, with leaves fully grown; the last ring on the tree was made in 2011. The bottom picture was taken on June 22, 2012, and has the rings marked by decades from 1950 to 2010. Also marked are the drought years of 1956 and 1988. Picture (digital; Image 2251).

Figure 124. The Mississippi Geological Survey helicopter at Ole Miss (left) and at airport (right). Image 2252.

on Mississippi agriculture led to the creation of an entirely new water law in 1985 (House Bill 762 and 149). The ring for the drought year of 1956 is unremarkable, while the 1955 ring is very small.

The small 1955 ring marks a local drought in Mississippi. It was part of a severe drought in the Mississippi Delta region from 1951-1954, which spurred a rush to drill water wells for crop irrigation. According to the Mississippi Board of Water Commissioners Bulletin 56-1 (page 8), by the end of 1955 more than 900 wells had been constructed. At this time the Mississippi Geological Survey had a cooperative agreement with the U. S. Geological Survey to conduct a statewide study of groundwater resources. This continued from September 1953 till July 1, 1956, when the Mississippi Board of Water Commissioners (a board created in response to the drought, and which in 1978 became the Office of Land and Water Resources) by legislative act became the state cooperator with the U. S. Geological Survey. The Mississippi Geological Survey helicopter (and Mississippi was the only state geological survey to have one at that time) was used during the drought to search for stream flow in north Mississippi streams (**Figure 124**). As for stream flow in the watershed containing the red oak in Figure 1, Mississippi Board of Water Commissioners Bulletin 61-1, page 3, recorded “Zero Flow Observed” on Bogue Chitto Creek at Tinnin, Mississippi, for the years 1952-1955.

Mississippi drought years of 1980-1982 (northern Mississippi), 1988, and 2012 also correspond to near record low river levels on

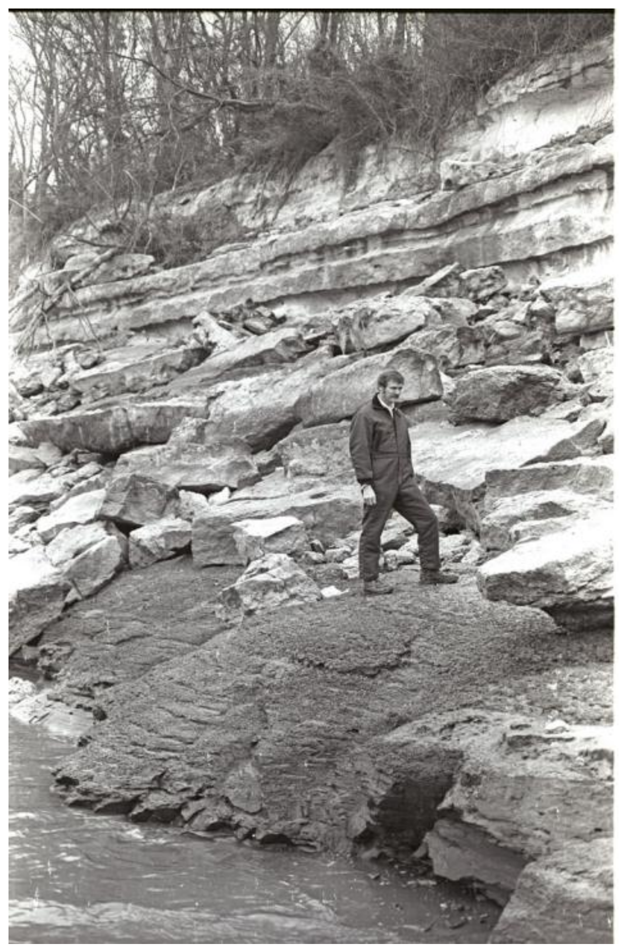


Figure 125. Jim May standing on the clays of the upper Forest Hill Formation during low water on the Mississippi at Vicksburg. Above in ascending order are the Mint Spring Formation (covered in talus), Marianna Limestone, and Glendon Limestone. Picture (negative 220-13; Image 2253) was taken in January of 1981.

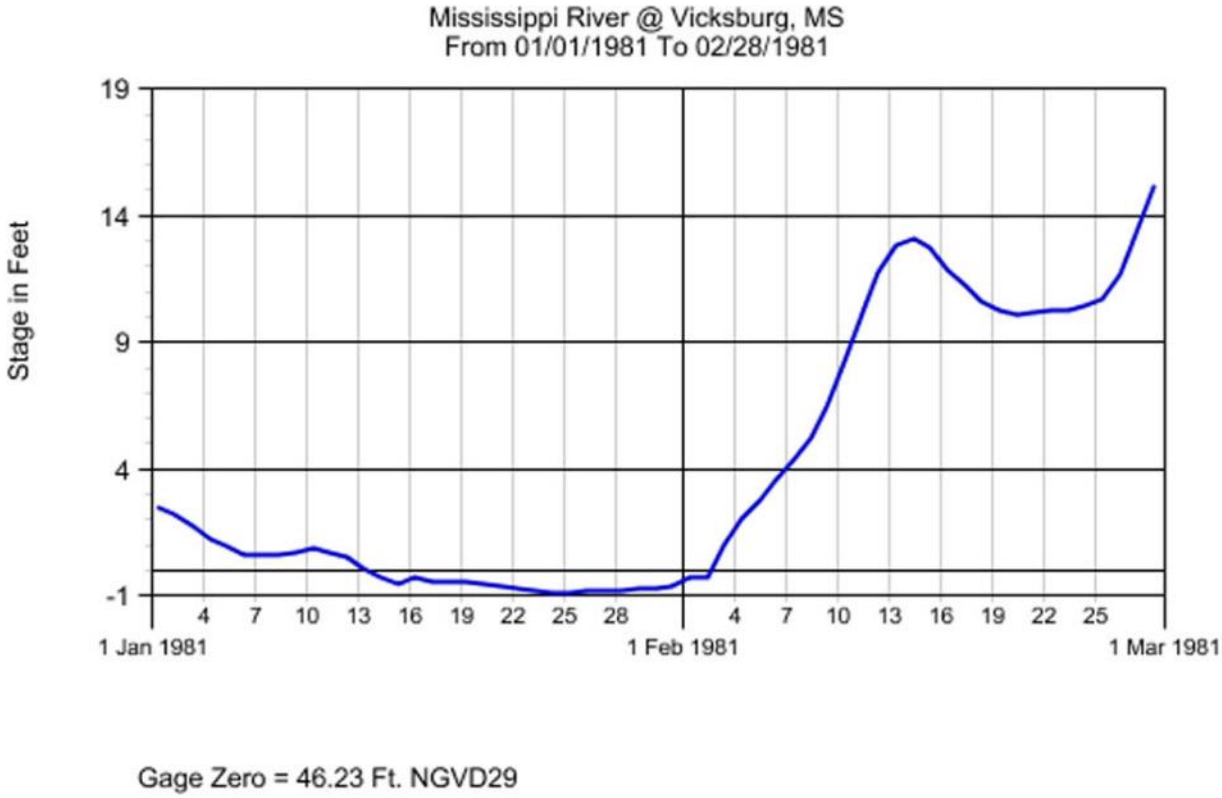


Figure 126. Mississippi River levels below the zero mark on the Vicksburg river gage in January and February of 1981, U.S. Geological Survey Water Data for the Nation. Image 2254.

Figure 127. Left, shell lag deposit at the base of the Mint Spring Formation with clay ripup clasts from the underlying Forest Hill Formation on the Mississippi River at Vicksburg. Right, clay of the upper Forest Hill Formation seen only at very low river levels. Pictures (scanned negatives at left 220-5 and at right 220-15; Image 2255) were taken in January of 1981.

the Mississippi River at Vicksburg. High-water levels at Vicksburg can be compared with floods of previous years by the historical flood crests marked on the Vicksburg flood-wall. But how does one compare low water marks with those from previous year (apart from having access to the river gage)? The geologic section exposed on the Mississippi River just north of the Ameristar Casino provides points of comparison (**Figure 125**). The section in descending order consists of: (1) hard ledges of Glendon Limestone, (2) a soft layer of Marianna Limestone, (3) fossiliferous, glauconitic sand of the Mint Spring Formation, including a concentration of seashells at the base of the formation, and (4) clays of the up-

Figure 128. At left, Michael Bograd with survey rod standing on the Glendon Limestone during low water on the Mississippi River at Vicksburg during the drought of 1988. The Marianna Limestone is exposed below the lower ledge of Glendon Limestone. At right, Michael Bograd standing at river level on the basal shell lag of the Mint Srping Formation. Pictures (left, slide 207-20; right, slide 207-4; Image 2256) were taken on June 28, 1988.

Figure 129. Left, James Starnes kneeling on the basal shell lag of the Mint Spring Formation on the Mississippi River at Vicksburg, with the overlying Marianna and Glendon limestone section to the left. At right, James Starnes standing on the basal shell lag of the Mint Spring Formation on the Mississippi River at Vicksburg, with the Highway 80 and Interstate 20 bridges at right. The river stage was at 1.6 feet at Vicksburg. Picture were taken on July 30, 2012; Image 2257.

per Forest Hill Formation. All of these formations were exposed in late January and early February of 1981 when the Mississippi River fell below the zero mark on the Vicksburg river gage (**Figure 126**). **Figure 127** shows the basal shell lag of the Mint Spring Formation (left) and the underlying clay of the upper Forest Hill Formation (right).

Figure 129 shows low water on the Mississippi River at Vicksburg, Mississippi, during the drought of 1988. At left in the figure, Michael Bograd stands on an exposed section of Glendon Limestone; at right, he is at river level on the basal shell concentration of the Mint Spring Formation. Figure 6 shows pictures of the same section at a river stage of 1.6 feet on July 30, 2012. The Forest Hill-Mint Spring contact shown in these figures is only seen at very low water (2 feet or less at the Vicksburg gage). Low river stages allow geologists to study and map formations that cannot be seen most of the time and also reveal structures such as large slump blocks that might impact buildings, bridges, and other infrastructure.

CHAPTER 4. SLOPE FAILURES

ENGINEERING GEOLOGY, THE YAZOO CLAY, AND THE SAINTS

The following is taken, in part, from the April 2009 issue of *Environmental News* Dockery (2009, p. 9-11).

Figure 130. Excavation for a new football field at Millsaps College at Jackson, Mississippi. The lower two tiers in the foreground consist of weathered Yazoo Clay. The upper tier is terrace sand, which drapes over the Yazoo Clay of the bottom tiers in the distant hillside. The crushed limestone floor is the foundation for a retaining wall. Extra stone is placed at the base of a small slump in the foreground. Picture (digital, CD 41; Image 1010) was taken on May 23, 2007.

Figure 132. Slump in Yazoo Clay pushed the retaining wall up and out as seen from the new football field at Millsaps College in Jackson, Mississippi. The slump scarp cuts near the observation tower of the upper field, and the toe is elevated in front of the retaining wall like a roll of carpet. Picture (digital, CD 42; Image 1011) was taken on January 31, 2008.

The selection of Millsaps College as a training camp for the New Orleans Saints was a thrill for many sports fans and a boost to the college. To accommodate the Saints' summer practice needs, the college contracted to expand their lower playing field adjacent to Woodrow Wilson Avenue. Dirt-moving work began in the spring and summer of 2007, and the field was expanded by cutting the toe of the hillside that separated the upper and lower playing fields. This work was done at a time

Figure 131. Excavation for a new football field at Millsaps College. The lower two tiers in the high-wall cut consist of weathered Yazoo Clay and the upper tier is a terrace sand deposit. The crushed limestone floor at the foot of the cut is the foundation for a retaining wall. Picture (digital, CD 41; Image 1087) was taken on May 23, 2007.

Figure 133. The manicured grass field at the toe of the slump, protruding from beneath the retaining wall at Millsaps College, looks like rolls of carpet. Picture (digital, CD 42; Image 1923) was taken on January 31, 2008.

Figure 134. Millsaps geology students watch as an auger rig drills a hole to determine the base of the slump block adjacent to the new football field at Millsaps College. Picture (digital, CD 42; Image 1012) was taken on February 20, 2008.

Figure 135. Excavation of slump block and removal of the tilted retaining wall. Each concrete block in the wall weighs 2,000 pounds and is fastened by dome and socket joints. Removed blocks are stacked in the foreground for reassembly later. Picture (digital, CD 42; Image 1013) was taken on June 4, 2008.

Figure 136. Construction of a 230-foot-long crushed limestone keway to disrupt the basal shear plane of the slump at Millsaps College. Picture (digital, CD 46; Image 1031) was taken on June 17, 2008.

Figure 137. Eastern terminus of 230-foot-long crushed limestone keyway surrounded by Yazoo Clay at Millsaps College. Picture (digital, CD 46; Image 1033) was taken on June 17, 2008.

of significant drought, which masked the problem of subsurface drainage from the upper field. A two-meter-high retaining wall, consisting of 2,000 pound concrete blocks fitted together like LEGO toys, was placed at the base of the cut hillside above a foundation of crushed limestone. **Figures 130-123** illustrate the geologic conditions in the freshly cut hillside; the three cut benches in the picture consist of a red terrace sand in the upper bench and weathered Yazoo Clay in the lower two benches. The terrace sand underlying the upper football field could not drain through the clay below, but only out the hillside. The underlying Yazoo Clay is the infamous, swelling, foundation destroying, road buckling, wall splitting, bane of the Jackson area. The Mississippi Office of Geology has published an environmental atlas of the Jackson area, containing geologic maps showing the surface outcrop of the Yazoo Clay. These maps are a must for prospective home buyers or builders. Once the retaining wall at Millsaps was built, it was backfilled with the excavated expansive Yazoo Clay and terrace sand.

Figures 132-133 show the spectacular failure of the retaining wall after the return of winter rains. While the wall held together, it did not stay put. At the top of the picture is the slump scarp, which threatened the filming tower and the upper field, and below is the slump's toe, which rose some five feet high

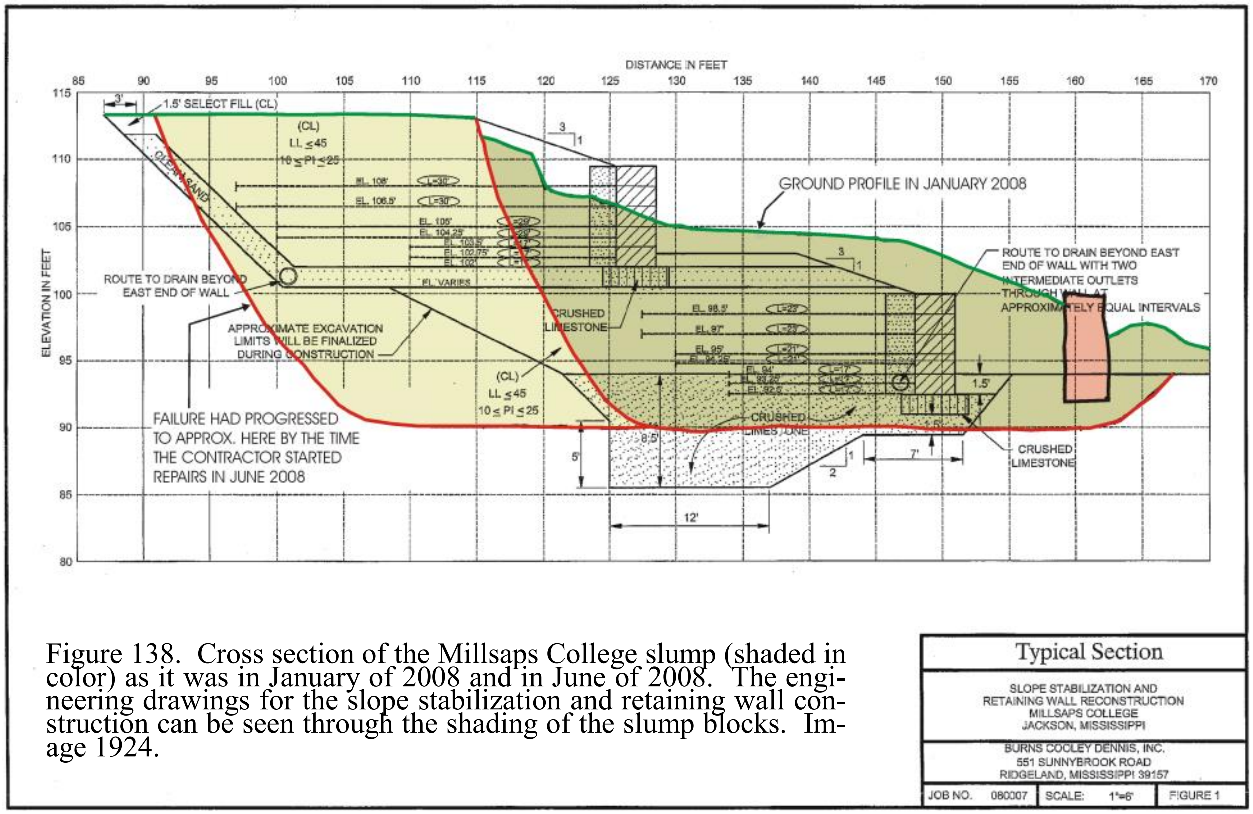


Figure 138. Cross section of the Millsaps College slump (shaded in color) as it was in January of 2008 and in June of 2008. The engineering drawings for the slope stabilization and retaining wall construction can be seen through the shading of the slump blocks. Image 1924.

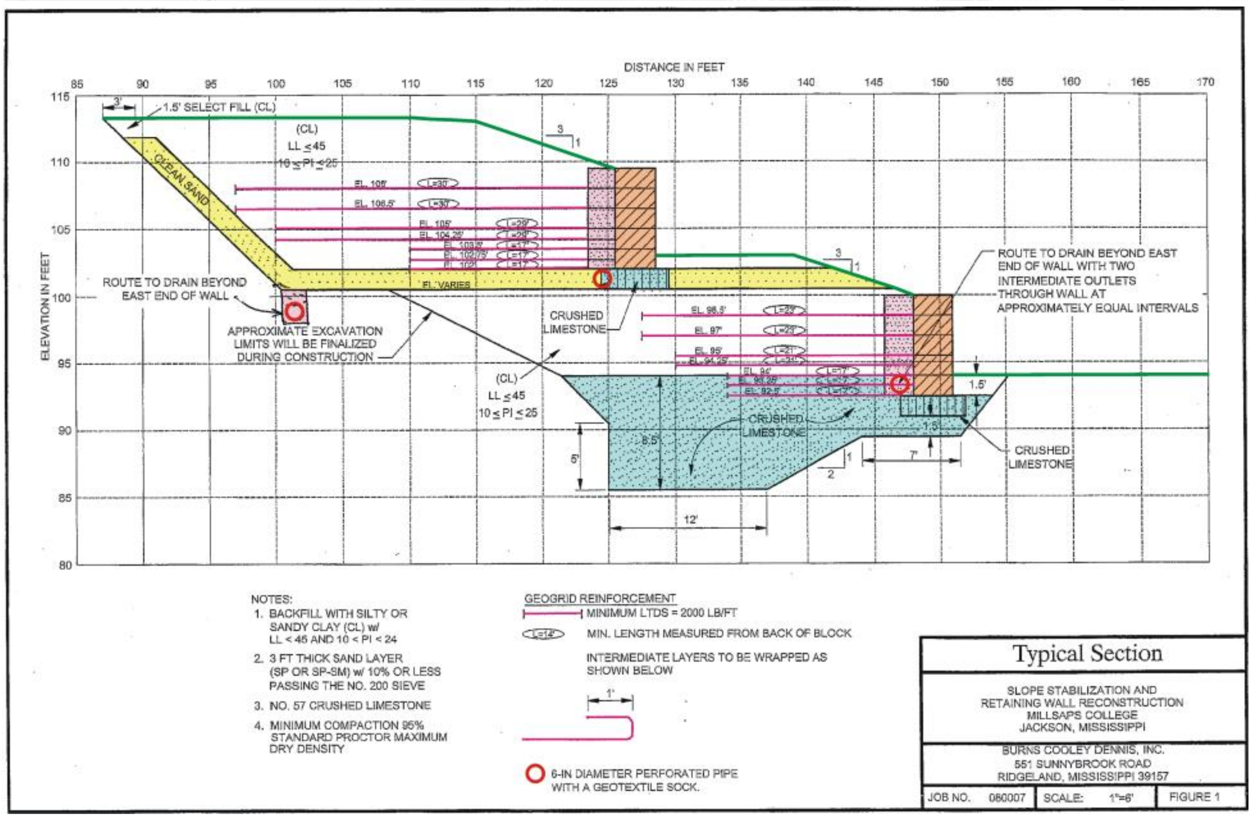


Figure 139. Engineering plans by Burns Cooley Dennis for slope stabilization and retaining wall reconstruction at Millsaps College. The repaired ground surface is in green, the sand chimney is in yellow, drains are in red, the crushed limestone keyway and retaining wall foundations are in blue, the retaining walls are in orange, the gravel fill behind the retaining walls are in light pink, and the layers of geogrid fabric are in hot pink. Image 1925.

Figure 140. Onsite conference concerning the construction schedule in preparation for the Saints' football summer training camp at Millsaps College. From left to right are Danny Neely (Millsaps College), Mike Early (Clear River Construction [CRC]), Jeb Boney (CRC), Terry Ashburn (New Orleans Saints), Mike Bolton (Burns Cooley Dennis), Kendrick Schetter (Millsaps), Dr. Todd Rose (Millsaps), and Nick Travis (President, CRC). Picture (digital, CD 46; Image 1034) was taken on June 17, 2008.

Figure 141. Geogrid plastic fabric is laid down behind the upper retaining wall at Millsaps College above a layer of sand fill. The sand chimney, which drains the cut face of the Yazoo Clay, can be seen along the left edge of the geogrid. The bulldozer is placing a silty soil above the geogrid. Picture (digital CD 47; Image 1037) was taken on July 1, 2008.

Figure 142. Bulldozer fills drain-line trench with sand to drain water away (to the east) from behind the upper retaining wall at Millsaps College. Picture (digital, CD 47; Image 1036) was taken on July 1, 2008.

Figure 143. Layers of geogrid fabric and soil are placed behind the upper retaining wall at Millsaps College. The geogrid fabric ties the layers into a coherent block that resists the fractures and shearing responsible for slope failures. Picture (digital, CD 47; Image 1038) was taken on July 2, 2008.

from the edge of the lower playing field. With the manicured grass surface, the toe looks like a roll of carpet (**Figure 133**). Before the Saints arrived for training camp, the displaced retaining wall needed to be rebuilt and the practice field repaired. The geotechnical firm of Burns Cooley Dennis, Inc., was employed to design a new retaining wall. **Figure 134** shows the drilling of a hole through the slump to determine the base of the failure surface or shear plane. Once the depth of the failure surface was known, the wall had to be removed block by block (**Figure 135),** the Yazoo Clay in the slump block had to be excavated and removed, and a crushed limestone keyway was built through the failure surface to prevent further movement (**figures 136-137**). **Figures 138-139** show Burns Cooley Dennis' engineering plans for the construction of the new retaining walls, and **Figure 140** shows a construction-schedule conference with concerned representatives from the college, the construction firm, the engineering firm, and the Saints.

Figure 144. Work on the Millsaps retaining wall stops for a conference. The crushed limestone keyway must be extended eastward an additional 115 feet, bringing the total footage of the reconstructed keyway and lower retaining wall to 345 feet. At right and facing the camera are project engineers Eddie Templeton of Burns Cooley Dennis (in sunglasses) and, at far right, Charles Furlow of Soil Tech Consultants. Picture (digital, CD 47; Image 1039) was taken on July 2, 2008.

Figure 145. Extending the reconstructed upper wall at the Millsaps College football field from 205 to 300 feet long. First the end of the wall was dismantled, the Yazoo Clay was excavated, the crushed-limestone keyway was extended, and then a sand chimney was placed behind the wall and fill dirt for drainage. Picture (digital, CD 55; Image 1067) was taken on July 15, 2008.

Figure 146. New retaining wall at Millsaps College completed in time for the Saints' summer football camp. The upper wall was extended from 205 to 300 feet to the east (left) of the stairs. Picture (digital, CD 55; Image 1066) was taken on July 22, 2008.

Figure 147. James Bridgforth, holding fossil oyster excavated from irrigation trench, Jared Meyers (right), and Rob Anders on trenching tractor, all with Lakeland Irrigation. James reported. "I'm doing the same thing I did last year." The main line of the first system was taken out by the slump. Picture (digital, CD 47; Image 1035) was taken on July 1, 2008.

The design of the new wall required: (1) a significant crushed limestone keyway, extending below the failure surface, to lock the surface in place, (2) lower and upper retaining walls, (3) a sand chimney to drain the upper playing field (**figures 141-142**), (4) foundation-quality fill material, and (5) geogrid plastic to bind the fill as a unit. **Figures 141** and **143** shows the emplacement of fill and geogrid behind the upper wall. As this work progressed, it was determined (**Figure 144**) that the retaining walls needed to be extended an additional 115 feet to the east to protect the slope and drain the water from behind the walls. To accommodate this, the east end of the just built retaining walls had to be dismantled (**Figure 145**). **Figure 146** shows the new retaining walls upon completion. The moral of this event can be summed up in a comment overheard from one of the workers reinstalling the irrigation system; the first system was taken out when the main line was ruptured by the slump. The worker (**Figure 147**) said, "I'm doing the same thing I did last year." Put in terms of a carpenter's adage: Neglect geologic (soil) testing and build twice; do geologic testing and build once.

THE DOGWOOD FESTIVAL SLUMP

The following is from the June 2009 issue of *Environmental News* (Dockery, 2009, p. 6-9).

The east entrance to Dogwood Festival Mall off of Highway 25 in Flowood, Mississippi, was cut into the east valley wall of the Pearl River flood plain with a rather steep slope. The Rankin County geology map by Wilbur Baughman and the unpublished Jackson SE 7.5-minute quadrangle map by David Thompson show this valley wall to be composed of Yazoo Clay in the lower slope up to an elevation of 350 feet above sea level with a terrace-sand deposit capping the hill top at 350 feet and above. Since the construction of the mall's east entrance, the slope has failed three times, the most recent failure occurring in February of 2009 (**Figure 148**). The 2009 slump event tore up a section of the road, curb, and storm drain, and required a permanent fix. In April of 2009 the failed soil of the slump was excavated (**Figure 149**) down to the unweathered Yazoo Clay bedrock (**Figure 150**) and removed. During and after dirt removal, (1) the cut was terraced, (2) a French drain was installed in the base of the cut and connected to the repaired storm drain, (3) the

Figure 148. Michael Bograd inspecting road damage caused by a slump along a steep slope on the east side of the east entrance to Dogwood Festival on Highway 25 in Flowood, Mississippi. Picture (digital, DVD 59; Image 1214) was taken on February 27, 2009.

Figure 149. Excavation of slump on the east side of the entrance to Dogwood Festival on Highway 25 in Flowood, Mississippi. Picture (digital, CD 59; Image 1215) was taken on April 20, 2009.

Figure 150. Unweathered Yazoo Clay in the bottom of excavation to remove slumped material along the east entrance for Dogwood Festival on Highway 25 in Flowood, Mississippi. Picture (digital, DVD 59; Image 1216) was taken on April 20, 2009.

Figure 151. Slump excavation is sealed in fabric and backfilled and compacted with a 96% pure grade of sand. Dogwood Festival can be seen in the upper right. Picture (digital, DVD 59; Image 1217) was taken on May 1, 2009.

Figure 152. Slump repair near completion with the storm drain repaired, the retaining wall in place, and the sand fill covered with fill dirt. Picture (digital, DVD 59; Image 1218) was taken on May 18, 2009.

Figure 153. Sand pit in terrace sand at Flowood, Mississippi, operated by A & A Excavation Contractors, Inc.—the source of the fill sand for the Dogwood Festival slump repair. Sedimentary structures such as cross bedding can be seen in the pit's highwalls. Picture (digital, DVD 59; Image 1219) was taken on May 8, 2009.

Figure 154. Terrace sand deposit at the entrance of Northwest Rankin Middle School at 5805 Highway 25 in Rankin County. Here the top of the terrace sand is about 400 feet above sea level. Picture (digital, CD 35; Image 1220) was taken on March 23, 2007.

cut was lined with geotextile (also called geofabric) held in place with metal pins, (4) the cut was backfilled with a sand chimney and fill, using a sand with less than 4% silt (or a greater than 96% pure sand) (**Figure 151**), (5) a retaining wall was installed with layers of geogrid and sand packed behind it, and (6) the sand chimney/fill was covered with fill dirt and top soil (**Figure 152**). Other than the sodding of the surface, the slump repair was largely completed in May of 2009.

The almost pure river sand used as fill for the slump repair came from a pit in a terrace deposit south of the Super Walmart on Highway 25. In **Figure 153**, a thick cross-bed set can be seen in the wall of this sand pit; similar sedimentary structures can be found in the point bars of modern rivers. Terrace sand is mined in several places along Highway 25 where it occurs at elevations between 350 and 400 feet above sea level and higher. This sand is usually of a reddish color and contains a greater silt and clay content than the sand shown in **Figure 154**. For a time, the 350-400-foot terrace sand composed a scenic butte at the entrance of Northwest Rankin Middle School (Figure 7), a setting that looked rather like an arid scene from the desert Southwest. This butte has been subsequently mined away.

A SLOPE TOO STEEP: SLUMPS IN THE YAZOO CLAY IN CENTRAL MISSISSIPPI

From the July 2010 issue of *Environmental News* (Dockery, 2010, p. 16-20).

The Yazoo Clay forms a physiographic region across central Mississippi known as the Jackson Prairie. This region consists of low rolling hills, mostly wooded with a mix of hardwoods and some pines, and some natural prairie land. The largest remaining natural prairie of the Jackson Prairie is the Harrell Prairie in Bienville National Forest in Scott County, a location selected for the September picture of Jerry Litton's *Narrative of Nature* calendar for 2010. When streams cut into the rolling hills of the Jackson Prairie, the Yazoo Clay of the cut bank fails in a series of en-echelon slumps until the slope reaches its natural grade. Such large slumps occur at Red Bluff on the east bank of the Chickasawhay River in Wayne County, just south of Shubuta.

So, what is the natural grade of a Yazoo Clay slope? I asked this question to Britt Maxwell of Maxwell Engineering in Jackson. Britt was also a classmate of mine (and of Michael Bograd) in geology at Mississippi State University and is one who has fixed many a failed structure on the Yazoo Clay. Britt said that he puts a slope no greater than 3:1 on the Yazoo Clay, but added that even this slope could fail though he hasn't seen it happen. Britt's 3:1 rule should apply: (1) whether a cut is made into a natural slope on Yazoo Clay, (2) whether a natural slope on Yazoo Clay is steepened with fill material, or (3) whether Ya-

Figure 155. Slump in Yazoo Clay on the north side of Interstate 20 west of Gallatin Street. Picture (digital; Image 1438) was taken on February 10, 2010.

Figure 156. Work crew excavates slump toe from Terry Road at Interstate 20 and erects concrete barriers to keep the toe off the road. Picture (digital; Image 1439) was taken on February 9, 2010.

Figure 157. Slump in Yazoo Clay on Terry Road at Interstate 20 in Jackson. Concrete barriers keep the slump toe off the road; the slump has fractured the concrete apron under the I-20 bridge. Picture (digital; Image 1440) was taken on February 10, 2010.

Figure 158. Rip-rap and concrete drain installed to prevent slumping in the Yazoo Clay on a road cut north of the Interstate 20 west-bound lane near Forest, Mississippi. Picture (color negative 568-0A; Image 344) was taken on March 1, 2006.

Figure 159. Slump in the Yazoo Clay on the east side of Interstate 220 South near the I-20 interchange. Picture (digital; Image 1441) was taken on February 10, 2010.

zoo Clay is used as construction fill.

To see the “slopes too steep” on the Yazoo Clay in central Mississippi, one only has to ride the Interstate 20/Interstate 220 loop at Jackson, where rains and cold weather have taken their toll. There is: (1) a slump on the north side of I 20 West just west of Gallatin Street, where the slope failure may be in Yazoo Clay used as fill, (2) one on the northwest corner of the intersection of I 20 and Terry Road, and (3) one on the east side of I 220 North just north of the intersection with I 20, where the Yazoo Clay may have been used as fill. The fourth slump of note is behind the new Farmer’s Market; this slump threatens to undercut Jefferson Street.

The I 20/Gallatin Street slump is a small one but has required frequent attention. This slump is sometimes patched up, and sometimes tolerated, but never fixed (**Figure 155**). The buff brown soil in the slump’s toe and seen in the mound of dirt drilled from the foundation of the light pole is weathered Yazoo Clay, which was perhaps used as fill in the construction of I 20.

The I 20/Terry Road slump is new and moved into the southbound lanes of Terry Road. Road crews excavated the toe of the slump from the road on February 9, 2010, and placed concrete barriers to prevent further movement onto the road (**Figure 156**). The slump fragmented the concrete apron of the I 20 bridge abutment as seen in **Figure 157**. Bridge abutments along I 20's right-of-way across the Yazoo Clay outcrop belt have had similar problems, as is evidenced by the rip-rap buttresses at bridge abutments beginning at Lake in Newton County to the east and continuing westward to just west of the I 20/I 220 interchange. One slope repair on the north side of I 20 near Forest, Mississippi, has a large rip-rap buttress and a system of underground and above-ground drains (**Figure 158**). The cost of this repair was such that one state worker claimed that for less money he could hire a bulldozer operator to work 24-7 to keep the slope in place.

The I 220/I 20 slump is new (**Figure 159**), but rip-rap to the south of it tells of a nearby slump that MDOT recently repaired with buttressing fill material (and the rip-rap toe). Together these slopes show that the interstate east slope is too steep. The Yazoo Clay involved in this slope failure may have been used as fill in the construction of this section of I 220; if so, it is Yazoo Clay fill on Yazoo Clay “bedrock.”

The Farmer’s Market slump was a new failure at a spot where a slump had been repaired just the previous year (**Figure 160**). The repair was an economical one that was not guaranteed as a permanent fix. This slump continued to grow and contained water in the sag ponds on top of the tilted slump blocks. The clarity of this water indicated that a broken city water main likely contributed to weakening of the soil and the resulting slope failure. The slump scarp endangered a water line and fire plug and was a threat to the integrity of Jefferson Street. When I took pictures of the slump, Dr. Zach Musselman brought his geomorphology class to the slump on a field trip (**Figure 161**). Geomorphology is a field in geology that studies the earth’s surface features and natural landscapes, a perfect class to be taught in Jackson’s slumping and changing terrain.

Figure 160. Slump in Yazoo Clay behind the new Farmer's Market. The slump scarp at top threatens a water main and Jefferson Street. Picture (digital; Image 1442) was taken on February 18, 2010.

Figure 161. Dr. Zach Musselman (far left) and his geomorphology class from Millsaps College examine the Farmer's Market slump. Picture (digital; Image 1443) was taken on February 18, 2010.

HOLDING BACK THE YAZOO CLAY AT THE FARMER'S MARKET

From the November 2010 issue of *Environmental News* (Dockery 2010, p. 14-17).

You've probably seen a wall built from bottom to top, but have you ever seen a wall built from top to bottom? It was a top-to-bottom wall that Burns Cooley Dennis, Inc., designed and Hayward Baker Geotechnical Construction built to hold back the Yazoo Clay at the Farmer's Market on the Fairgrounds at Jackson, Mississippi. This is the same team that worked together to build the hundred-foot-high retaining wall along the bluff line at Natchez and the retaining wall on the bluff side of the Ameristar parking lot at Vicksburg.

On April 8, 2009, I went to see the newly repaired slope below Jefferson Street and behind the Farmer's Market parking lot. Yazoo Clay had been removed from the failed slope and replaced with non-expansive fill dirt, which was freshly landscaped at the time. Less than a year later on February 10, 2010, I returned to see a complete failure of that same slope (see the May 2010 issue of *Environmental News*, page 20). At risk were the Farmer's Market parking lot, Jefferson Street, and water mains beside and under Jefferson Street. The repair design to fix the failed slope was a shot-

Figure 162. Left: Adding and compacting fill material to the upper slope behind the Farmer's Market on July 19, 2010. Right: New failure in the Yazoo Clay of the upper slope the following day on July 20, 2010. Pictures (digital; Composite Image 1681).

Figure 163. Left: The yellow cross marks the spot for drilling the hole for the second soil nail in the upper tier of the Farmers Market retaining wall. Right: Rebar protrudes from five holes, while a sixth hole is being reamed out. The white hose is for pumping grout. Pictures (digital; Composite Image 1682) were taken on July 28, 2010.

crete wall anchored by soil nails. The term "soil nail" is not the most reader-friendly term to explain the structures that secured the wall. Soil pilings better describe the 35 to 45-foot-long grouted-rebar structures that are drilled, inserted, and grouted at a 10-20 degree angle to the horizon. Some 160 soil nails were placed to hold the shotcrete wall, a welded-wire-mesh-reinforced wall that would be only about 6 inches thick. A photographic record of the wall's construction was kept from July 19 to August 16, 2010, as shown in the accompanying figures.

The upper tier of the wall was constructed first with soil nails at a 20-degree slope below the horizon and on centers spaced four to five feet apart. The middle and bottom tiers of the wall had soil nails with a 10-degree slope and with a similar spacing. Soil nails had a vertical spacing of about five to six feet. The finished wall had a 1 to 2 slope, one foot horizontal for two feet vertical, and the grassed slope at the base of the wall was 6 to 1, six feet horizontal for each foot vertical. **Figure 162** shows the dirt work in preparation for the wall construction. **Figures 163-165** show the construction of the wall's upper tier. After this

Figure 164. Left: Rebar and spacers for soil nails. Right: Forms, grouted rebar (soil nails), and welded wire mesh of the upper tier of the Farmer's Market retaining wall. Pictures (digital; Composite Image 1816) were taken on July 28 (left) and July 31, 2010.

Figure 165. Left and right: Spraying shotcrete onto the welded wire mesh of the upper tier of the Farmer's Market retaining wall. Pictures (digital; Composite Image 1817) were taken on August 2, 2010.

construction, an afternoon storm complicated work as water poured out from behind the wall at the contact of the Yazoo Clay and adjacent fill material (**Figure 166**, left picture). When the rain stopped, the water flow continued, leading to the discovery of a leak in a 6-inch city water main behind the wall. This leak was repaired by the city, and the leaky south end of the middle tier was sealed with shotcrete.

Figures 166 and 167 show the construction of the middle and lower tiers of the retaining wall, including the effort to insert rebar into drill holes after a rainstorm. **Figure 168** shows the wall's finishing touches as it is sprayed over with a buff-brown grout to make it look natural, like dirt. When you shop at the Farmer's Market, be sure to see the newly landscaped wall.

MORE SLOPES TOO STEEP AND OTHER YAZOO CLAY PROBLEMS

From the July 2012 issue of *Environmental News* (Dockery 2012, p. 16-19).

The July 2010 issue of the MDEQ newsletter contained an article entitled "A

Figure 166. Left: Workers hurry to insert rebar into drill holes in the south end of the middle tier after an afternoon storm sends water pouring in from behind the wall at the contact of the brown Yazoo Clay and red fill dirt just to the right of the man at far left. A leak in a 6-inch city water main was discovered, which contributed to the flow; the leak was repaired by the city that evening. Right: Cement truck pours shotcrete into hopper where it is pumped through a hose and sprayed onto the soil nails and welded wire mesh on the troubled south end of the middle tier to seal the leak site behind the Farmer's Market retaining wall. Pictures (digital; Composite Image 1818) were taken on August 4 (left) and August 6, 2010.

Figure 167. Left: Welded wire mesh is checked before shotcrete is sprayed on the north end of the wall's middle tier. The black vertical strips are drains to prevent the accumulation of water behind the wall. Right: Holes are drilled for the soil nails of the lower tier of the Farmer's Market retaining wall. Drain pipes are visible at the base of the wall. Pictures (digital; Composite Image 1819) were taken on August 9 (left) and August 11, 2010.

Figure 168. Left: Shotcrete is sprayed onto the welded wire mesh of the lower tier of the Farmer's Market retaining wall. Right: A brown dirt-colored grout is sprayed over the entire retaining wall to give it a natural appearance (like dirt). Water drains can be seen protruding from the base of the wall. Pictures (digital; Composite Image 1820) were taken on August 12 (left) and August 16, 2010.

slope too steep: slumps in the Yazoo Clay in central Mississippi." The slumps mentioned were those along Interstate 20 and 220 in the Jackson area and the slope behind the Farmer's Market in Jackson. These slope failures have now been repaired. However, other slope and foundation problems have taken their place, some of which are chronicled below.

On May 21, 2005, the final two gaps in the Natchez Trace Parkway, a two-lane federal roadway between Natchez, Mississippi, and Nashville, Tennessee, were opened to traffic. These newly completed segments were: (1) the Jackson bypass connecting Interstate 55 and Interstate 20 and (2) a segment connecting Liberty Road in the city of Natchez and U.S. Highway 61 near Washington, Mississippi. Just seven years after opening, a portion of the Jackson bypass route was closed on March 15, 2012, due to a slope failure on the Yazoo Clay near milepost 94.8 just south of where the Trace crosses West County Line Road. In 2011, the roadway at this point developed a large crack that separated the two lanes of traffic. Several repairs were made to the road surface that year, but movement along the crack continued to the point that the road was deemed unsafe for vehicular traffic (**Figure 169**). Some 13,000 cars per day travel the Natchez Trace between Jackson and Clinton; it was feared such heavy traffic could contribute to the road problem. Repairs were estimated to take about a year and to cost about one million dollars.

Figure 169. Failed road surface on the Natchez Trace Parkway along a steep slope near the County Line Road overpass in Jackson, Mississippi. Pictures (digital; Composite Image 2243) were taken on March 14, 2012, the day before the road was closed to traffic.

Figure 170. Progressive slope failure on the west side of the Walmart parking lot on Highway 80 in Clinton, Mississippi. The picture on the left was taken on March 14, 2012, and the picture on the right with the addition of a set-back concrete curb was taken on April 9, 2012 (Composite Image 2244).

Figure 171. The toe of the slump at left fills part of the store's storm-water runoff basin. The scarp on the slump's south flank has deflected the original curb and water line at a 30 degree angle. The picture on the left was taken on April 10, 2012, and the picture on the right was taken on April 9, 2012 (Composite Image 2245).

The west slope bounding the Clinton Walmart parking lot on Highway 80 began a slow and progressing failure at the beginning of 2012. At first, warning cones were placed around the failure; added to this was a concrete curb offset some 15 feet from the failed curb (**Figure 170**). The toe of the slump filled in part of the store's storm-water runoff basin, and the scarp on the south flank deflected the original curb and water line at a 30 degree angle (**Figure 171**). The scarp on the north flank of the slump pulled on optical fiber cables (communication lines), displaced the power pole, and displaced a gas line (**Figure 172**).

The Mississippi Department of Public Safety headquarters building near the intersection of Interstate 55 and Woodrow Wilson Drive underwent repairs this year after the Yazoo Clay closed the crawl space under the floor and lifted the floor and its 20-foot-deep pilings and lifted and sheared the exterior wall from its pilings. New pilings were constructed for the exterior walls, and a new crawl space was dug under the floor. **Figure 173**, at left, shows an exterior wall set on new pilings, and, at right, a conveyer belt removing weathered Yazoo Clay as workers dig a new crawl space. **Figure 174**, at left, shows the remains of one of the original exterior pilings and, at right, shows the offset between the floor slab, which was lifted by the Yazoo Clay, and the exterior walls.

Figure 172. At left, the scarp on the slump's north flank cuts at the base of a telephone cable box, displaces a power pole, and (at right) cuts across a buried gas line. Pictures (digital; Composite Image 2246) were taken on April 9, 2012.

Figure 173. At left, the exterior wall of the Department of Public Safety rests on new pilings; a water cooler rests on the nearest piling, which is marked with the number 5 above. At right, a conveyer belt removes Yazoo Clay as workers dig a new crawl space beneath the floor slab. Picture (digital; Composite Image 2247) were taken on May 7, 2012.

Figure 174. At left is the remains of one of the original exterior wall pilings. At right is the floor slab, which has been lifted about half a foot above its original position in relation to the exterior wall. Pictures were taken on May 7, 2012.

LOESS ART AND SLOPE FAILURES

The loess art section is, in part, from the February 2011 issue of *Environmental News*, (Dockery, 2011, p. 16-18).

The Loess Hills Physiographic Province, a band of rugged hills on the eastern edge of the Mississippi River Alluvial Plain, is underlain by a thick sequence of windblown silt called loess. The hills around Vicksburg, Mississippi, are capped in loess cover that can be as much as one hundred feet in thickness. The loess was deposited during the last ice age some 18,000 years ago and has a rather unique property in that it is stable when cut as a vertical wall (**Figure 175**). Such cuts are often smoothed to the appearance of a plastered wall to prevent rain and sheet wash from following any irregularity and causing erosion. Loess cuts thus make a wonderful canvas for those who wish to carve their initials or for those who wish to create art—loess art. It was a loess canvas that led to the mysterious writing on the wall in 1973 as recounted below.

For those who regularly travel I 20, the mysterious writing appeared on February 3, 1973, in letters elevated ten feet above ground level, seven feet in height, and stretching 100 feet in length reading: "REMEMBER DUANE ALLMAN." Duane Allman was co-founder, with his brother Gregg, of the Allman Brothers Band. In 2003 *Rolling Stone* magazine listed Duane as number 2 (behind Jimi Hendrix) on a list of the alltime greatest guitarists. But Duane's career was cut short in a fatal motorcycle accident on October 29, 1971. A little more than a year later, the writing on the wall appeared. It received international notice when it was featured in the April 11, 1974, issue of the *Rolling Stone* magazine. Of geologic interest was that the writing was carved in a vertical wall of loess, and thus was a form of "loess art."

This deed was recounted in the October 15, 2007, edition of *The Vicksburg Post* in a front-page article by Eric Brown entitled "4 who carved Allman tribute remember a star." The "4" were freshman college students attending Hinds Junior College: David Reid, Dennis Garner, Don Antoine, and Len Raines. They passed a vertical, almost pristine, wall of loess, located on the north side of the I 20 westbound lanes some six miles east of Vicksburg near the Bovina exit, on their daily commutes to classes at Hinds; it was during these commutes that they planned their tribute. According to a typed account by Reid just after the event, the carving began at 8:45 a.m. Saturday, February 3, 1973. They unloaded picks, axes, and a 9-foot ladder on a beautiful clear day, and, within four and a half hours after its initiation, the tribute was finished. They then signed their names in the loess. Though the message turned out OK, the group avoided disaster halfway through when it came to their attention that the second M in REMEMBER was missing. **Figures 176 and 177** show the finished inscription. **Figure 178** shows the four artists by their work just before carving the last R in REMEMBER. The carving is no longer visible. **Figure 179** shows a tribute to Pink Floyd carved in loess on Interstate 20 near Vicksburg, and **Figure 180** shows more recent loess art on Highway 49 south of Yazoo City. Elements in the later artwork include "YAZOO," a winking smiley face, and an angel.

Figure 175. Apartments above a vertical loess bluff on the Interstate 20 frontage road at Vicksburg, Mississippi. Picture (digital; Image 1329) was taken on September 29, 2009.

Figure 176. View of Allman tribute from Interstate 20 some six miles east of Vickburg, Mississippi. Image 1846.

Figure 177. Carving in loess on Interstate 20 near Vicksburg: "REMBER DUANE ALLMAN," signed and dated 2-3-73. Picture (Image 1847) is from the front page of the October 15, 2007, issue of The Vicksburg Post.

Figure 178. The four Hinds Junior College students, David Reid (top), Don Antoine (bottom left), Dennis Garner (bottom middle), and Len Raines (bottom right), who carved the "Remember Duane Allman" tribute in the loess near Vicksburg, Mississippi, on February 3, 1973. Picture (Image 1848) was taken by Don Antoine on February 3, 1973.

Figure 179. Loess art in road cut on Interstate 20 near Vicksburg, Mississippi. At top is a brick pattern with "PINK FLOYD" carved into the pattern and sprayed pink. The album The Wall, one of the best-selling albums of 1980, is inscribed to the right. Picture (scanned print; Image 1878) was taken by R. D. Bickerstaff in the mid 1980s.

Figure 180. Close up view of loess art on the west side of Highway 49 south of Yazoo City and north of the Myrleville Road intersection. Picture (digital; Image 926) was taken on July 25, 2007.

While most of the loess is eolian (windblown) dust from glacial-melt-water deposits that once covered the Mississippi River Alluvial Plain, some loess deposits are water lain. Water-lain loess deposits are reworked eolian loess from within the drainage basin and can be distinguished by a fauna of freshwater snail shells and mussel shells as opposed to the land snail fauna of the typical eolian loess. The bottoms of loess channels often contain buried logs and wood debris and may contain sand and gravel. The latter present opportunities for piping of sediment within the loess hills. Water-lain loess is the likely source of the diverse Pleistocene land-mammal fauna within the loess.

Piping. Piping of water and sediments is a problem in loess cover over pre-loess sand and gravel deposits. Springs issuing from the pre-loess deposits create sinkholes in the loess cover. Filling these holes with hauled in dirt may result in that dirt moving down the piping channel and reappearing in a spring at the toe of the hill. I've had a dump-truck load of dirt disappear this way over time. A small hole at the surface may widen as a large cavity at depth. Loess sinkholes are hazards to pedestrians and tractor work alike. As for tractor owners in the loess hills, it's best to work your own property where you know the sinkholes sites, rather than to work on a neighbor's property where you don't.

Engineering Problems. Many problems with loess soils have occurred along the bluff line adjacent the Mississippi River Alluvial Plain, especially along U.S. Highway 61. George Lemon, formerly an engineer with the Mississippi Highway Department, gave an account of slides on the east bank of the Yazoo River in the winter and spring of 1946 that destroyed the approach spans of the Highway 61 bridge at Redwood in Warren County, Mississippi (Dockery, 2004a). A large slump in loess overlying the Vicksburg Group cut out a section of the south-bound lane of Highway 61 in Vicksburg south of Interstate 20 in the spring of 1978 (**figures 181-182**). The same section of this lane was closed for maintenance again in 2006 to prevent a potential slope failure. Work on the new four-lane section of Highway 61 at Cannonsburg in Jefferson County in the fall of 2004 caused a slump in loess overlying a smectitic Miocene clay, which undercut the foundation of the Keating house on the hilltop above (Gates, 2004; Dockery, 2005) (**Figure 183**).

Loess soils have caused foundation problems along rail lines at the International Paper Plant on Highway 3 north of Redwood in Warren County, Mississippi, and north of Flora in Madison County, Mississippi, the site of an Amtrak derailment on April 6, 2004, that caused one fatality and many injuries. Mitchell (2004) quoted an ex-railroad administrator, concerning loess foundations related to the Amtrak derailment, that the loess "doesn't seem to pack itself down." There were four

Figure 181. Failure of Highway 61 southbound lane in Vicksburg, Mississippi, south of Interstate 20 due to a large slump in the loess overlying the Bucatunna Formation. Picture (Kodachrome slide 15-21; Image 538) was taken on May 31, 1978, as viewed looking north.

Figure 182. Failure of the Highway 61 southbound lane in Vicksburg south of Interstate 20 as viewed looking south. Here a large slump in the loess has caused a drop of about 20 feet where the fault scarp cut the highway. Picture (Kodachorme slide 15-20; Image 539) was taken on May 31, 1978.

Figure 183. Slump in loess and underlying Miocene clays cutting into the foundation of the Keating house on Highway 61 at Cannonsburg in Jefferson County. The slump occurred when the toe of the hill was cut to expand the highway. Picture (color negative 536-20; Image 334) was taken on November 16, 2004.

Figure 184. Slump in loess at Vicksburg, Mississippi, where the toe of the slope was cut during the construction of a new railroad track. Picture (color negative 574-23; Image 317) was taken on March 21, 2006.

freight train derailments between 1989 and the Amtrak derailment within five miles of the Amtrak wreck.

In Vicksburg, Mississippi, in 2005 and early 2006, the toe of a loess covered hillside near the east bank of the Mississippi River was cut in the construction of an additional railroad track for the Kansas City Southern Railway. Following heavy rains in March of 2006, the slope moved, leaving backyards cut by slump scarps and endangering the city's water main, gas line, several private communication cables, and a major high-voltage transmission line, all located along the railroad right-of-way (**Figure 184**). Residents of a nine-block area along Pearl Street were warned to prepare for evacuation should additional mudslides occur (Hinton, 2006). A substantial retaining wall was built at the back of the Ameristar parking lot in Vicksburg to hold the base of a loess bluff in place (**figures 185-186**).

Russell (1935) reported a landslide two miles south of Fort Adams, Mississippi, which

Figure 185. The Ameristar parking lot and retaining wall cut into the loess bluff adjacent the Mississippi River at Vicksburg, Mississippi. Picture (digital, DVD 98; Image 1877) was taken on September 9, 2009.

Figure 186. Retaining wall, consisting of soil nails, steel framework, and treated wooded planks, at the toe of the loess bluffline at the Ameristar Casino in Vicksburg, Mississippi. Picture (digital; Image 1330) was taken on September 26, 2010.

Figure 187. Retaining wall at Natchez, Mississippi, built to protect the upper loess section along the Mississippi River bluff line from slope failure. Picture (digital, CD 37; Image 968) was taken on April 21, 2008.

Figure 188. Retaining wall along the Mississippi River bluff line at Natchez, Mississippi, built to protect the loess section of the upper bluff from slope failure. Picture (digital, CD 37; Image 974) was taken on April 21, 2008.

Figure 189. A section of the retaining wall at Natchez, Mississippi, where houses are within 100 feet of the bluff due to slope failures that produced landslides. Picture (digital, CD 37; Image 967) was taken on April 21, 2008.

Figure 190. Houses at Natchez, Mississippi, within 100 feet of the edge of the bluff line. The fence along the edge of the retaining wall protects pedestrians from an 80-foot dropoff to the base of the wall. Picture (digital, CD 37; Image 977) was taken on April 21, 2008.

occurred during dry weather and low river stage on October 8, 1933, that was so sudden and on such a large scale "that people fled their homes in terror from the roar and shaking of the ground." The landslide left a typical crescentic slump scar in a bluff that rose 270 feet above the level of the Mississippi River. A plane-table survey indicated an affected area of 97 acres in which the ground contained "an intricate pattern of horsts, grabens, and tilted blocks, with axial trends chiefly parallel to the river bank and local relief varying up to 100 feet."

Natchez Bluff Landslides. Smith (1986) reported results from a geological investigation conducted at Natchez, Mississippi, to determine failure mechanisms responsible for the failure and retreat of the Natchez bluff, which rises 150 to 200 feet above the adjacent Mississippi Alluvial Valley. In ascending order, the bluff is composed of a thick deposit of loess, a complex fluvial deposit composed of beds of clay, silt, sand and gravel in the Natchez Formation, and a Miocene hard clay shale in the Hattiesburg Formation. Failure mechanisms included rotational slumping of various scales, soilfall, soil slide, solifluction, mudflow, and erosion by surface wash (**Figure 191**).

Vestal (1942, p. 72) reported a slump at Natchez on September 20, 1939, when "three slides in quick succession carried into the river a mass of earth 200 feet wide and 100 feet deep." This landslide killed one person and destroyed almost the entire sawmill plant of the J. M. Jones Lumber Company, which was located on an alluvial bench some 200 yards from the base of the bluff. Vestal noted that slumping was especially active during times of low water on the Mississippi River.

A significant mudslide at Natchez, Mississippi, on March 29, 1980, damaged two historic buildings in the Natchez-Under-the-Hill area and killed two people. This event, coupled with the fact that historically significant areas in Natchez were now very near the bluff edge, led Congress to authorize a study of the bluff to be performed by the United States Army Corps of Engineers under the supervision of the National Park Service (U. S. Army Corps of Engineers, The Natchez Bluff Study, 1985). The report listed relatively recent slope failures, which included: (1) a slide on March 30, 1949, that resulted in closing some sections of Clifton Avenue, (2) a major slide in 1951 that destroyed a section of Clifton Avenue and forced the closing of all street traffic (this slide may have been caused by a leaking storm sewer), (3) a slide in 1978 that resulted in the loss of a private bluff stabilization structure in an area northwest of Weymouth Hall, and (4) the slide of March 29, 1980, that killed two people. The area northwest of Weymouth Hall had experienced intermittent slides that claimed about 90 feet of the bluff. Weymouth Hall, which was located in a section where the bluff had retreated approximately 82 feet since 1864 due to soil falls and soil slides, was within 7 feet of the bluff's edge.

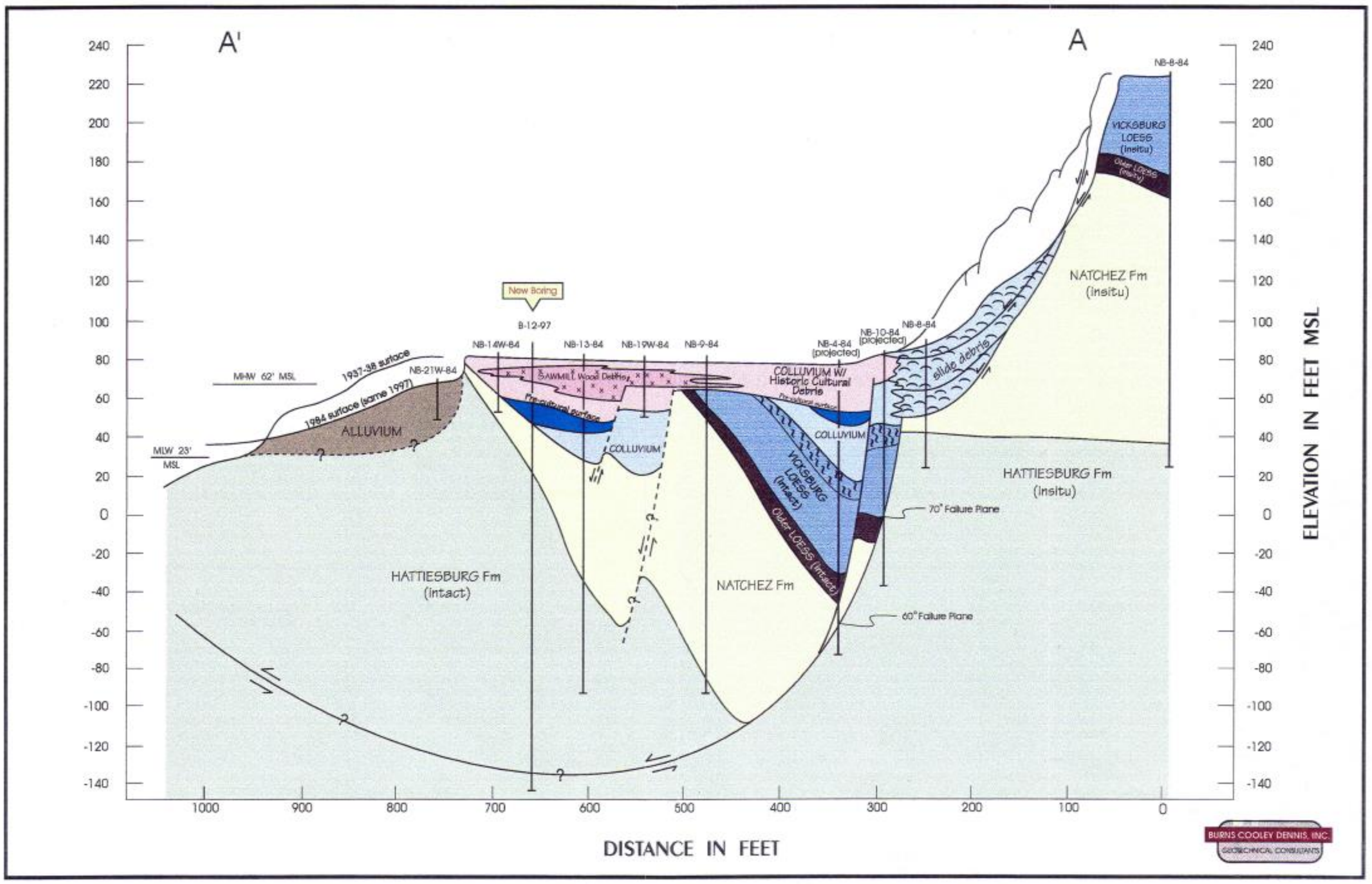


Figure 191. East-West cross section D-D' from the Mississippi River to Clifton Avenue in Natchez, Mississippi, showing buried slump blocks along the Natchez bluff line. Cross Section by Burns Cooley Dennis, Inc. Image 697.

A newspaper report of the March 29, 1980, mudslide at Natchez incorrectly reported three rather than two people dead (Clarion-Ledger/Jackson Daily News, 1980). One fatality was in the collapse of the Under-The-Hill Salloon, a 19th-century bar. Some 30 to 35 people were in the bar at the time. A witness to the landslide was standing on his boat dock when he saw the bluff begin to slide toward the buildings. The witness said, "I started screaming but they couldn't hear me. People were flying all over the place." A patron in the bar reported that "the mud and debris was 'like a tidal wave' that knocked many of the 30 to 35 persons out the windows in the front of the two-story brick building."

In 1997, the largest public-works project in the history of Natchez was underway to save the bluffs with $5 million in funds from the USDA National Resources Conservation Service and $18.5 million from the U.S. Senate (Lucas, 2004). Beginning in 1998 and ending in 2001, the U. S. Corps of Engineers supervised work to stabilize the bluffs at Natchez from the Clifton Avenue area to Silver Street. Work was completed in 2002 to stabilize the bluff below Roth Hill Road. The bluff stabilization project consisted of "high-tech" retaining walls with pipes every six feet to drain water from the behind the walls (McCann, 2002).

In March of the following year, heavy rains caused mudslides and sinkholes so numerous that the city engineer lost count. Though the retaining walls held, five slides along Learned's Mill Road and two slides along Roth Hill Road damaged some of the pipes that drained the retaining walls (McCann, 2003). In January of 2005, the City of Natchez was seeking a corps grant for $1 million for additional bluff stabilization, where leaks in deteriorated plastic drain pipes eroded two large holes at the bottom of the bluff below Learned's Mill Road (Picayune Item, 2005). **Figures 187-189** show the Natchez retaining wall, and **Figure 191** gives a cross section from the Mississippi River to Clifton

Figure 192. Drilling through a slump block under the Mississippi River between the Interstate 20 and Highway 80 bridges at Vicksburg, Mississippi. Picture (scanned print; Image 1798) taken by Mark Teague.

Figure 193. Close-up view of the truck-mounted drilling rig on a barge, drilling through a slump block under the Mississippi River between the Interstate 20 and Highway 80 bridges at Vicksburg, Mississippi. Picture (scanned print; Image 1799) taken by MarkTeague.

Avenue above the bluff line in Natchez. The cross section shows ancient slumps in front of the bluff line that extend beneath the Mississippi River.

capped by 15 feet of Glendon L

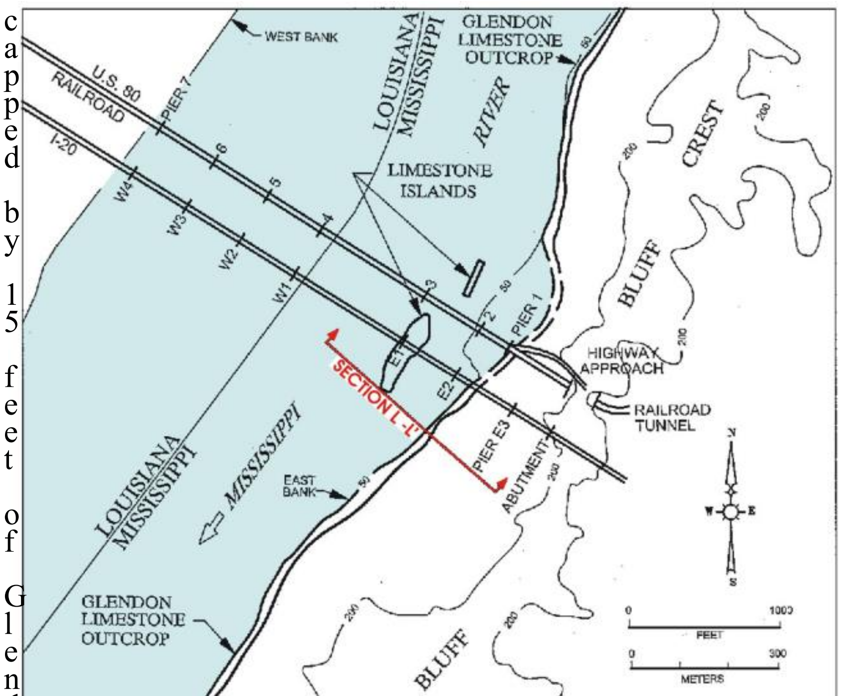


Figure 194. Location map from cross section of slump block on the Mississippi River and bluff line at the Interstate 20 and Highway 80 bridges at Vicksburg, Mississippi. Map was prepared by Richard J. Lutton, geological engineer, for Burns Cooley Dennis, Inc. (Image 1832).

Slump at the Interstate 20 and Highway 80 Mississippi River bridges. During construction of the Highway 80 Bridge in the 1930s, the bridge moved while it was being built and thereafter. In December of 1938 the bridge moved west some 9 inches. The bridge moved again some 4 inches in December of 1993 and continued moving until it reached a cumulative movement of 23 inches by December of 2004. The latter movement was a result of construction work on the Ameristar Casino, which involved cut and fill at the base of the bluff line (**Figure 186**). The westward relocation of fill dirt not only reactivated movement on the Highway 80 bridge, but caused movement on the southern end of the Ameristar property and the movement of two piers on the Interstate 20 Bridge. The top of Pier E-2 of the Interstate 20 Bridge moved westward some 6 inches between December of 2000 and May of 2001; at this same time Pier E-1 moved westward some 6 to 9 inches. In response to this movement, bridge modifications were undertaken from March to June of 2004 to open bridge joint PP 15 about 9 inches. These piers moved another inch in 2012 in response to low river levels. Superintendent of the Vicksburg Bridge Commission, Herman Smith, reported to WAPT News (August 6, 2012) that every time the river dries up there is movement to the west.

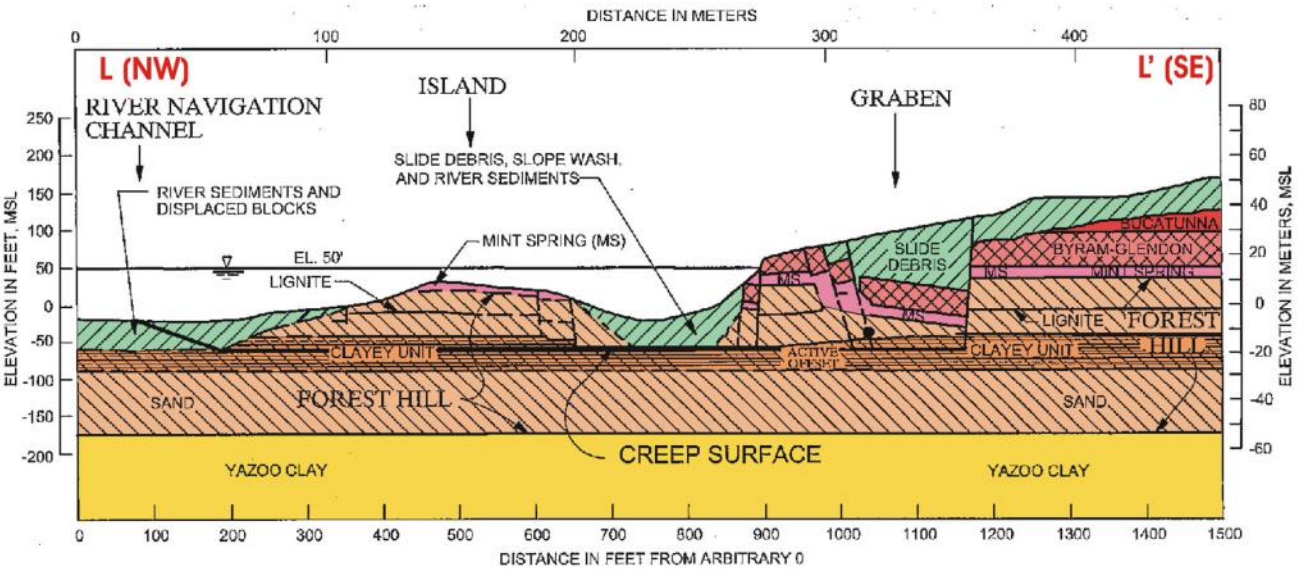


Figure 195. Cross section of slump block on the Mississippi River and bluff line at the Interstate 20 and Highway 80 bridges at Vicksburg, Mississippi. Cross section was prepared by Richard J. Lutton, geological engineer, for Burns Cooley Dennis, Inc. (Image 1831).

Figure 196. Left, construction of the new retaining wall at the south end of the Ameristar property. Right, drilling a 200-foot-long anchor into the base of the retaining wall. The Highway 80 and Interstate 20 bridges are in the background. Pictures (digital; Composite Image 2258) were taken on July 30, 2012.

Figures 192-193 show the drilling of a test hole in the Mississippi River at the Interstate 20 and Highway 80 bridges. The Mississippi Office of Geology ran geophysical logs on this test hole with the logging van on land and the wireline tools ferried to the barge. An earlier test hole, borehole B4, was logged with the van operating from the Interstate 20 bridge, blocking one lane of traffic, and with a spotter at the well head on the barge below. **Figure 194** shows the location of the Interstate 20 and Highway 80 bridges and the location of the cross section in **Figure 195**. To halt movement on the southern end of their property adjacent the Highway 80 Bridge, Ameristar Casino began construction of a concrete retaining with 70-foot-deep closely-spaced vertical steep piers in its footing and 200-foot-long anchors drilled at a 10 degree angle to intersect the Glendon Limestone (**Figure 196**).

Figure 197 (at left) shows the Glendon Limestone in place below the Interstate 20 bridge on the Mississippi River's west bank. At right in Figure 1 is a natural island (exposed only at lower water) on the east side of Pier E-1. This island is composed of a doubly-plunging, north-south-oriented anticline


Figure 197. Left: Exposure of Glendon Limestone on the east bank of the Mississippi River beneath the Interstate 20 bridge at Vicksburg. Right: An island of Glendon Limestone in a laterally displaced and down-thrown block, rising out of the river on the south (left) end and plunging beneath the water on the north end in front of Pier E-1 of the I-20 bridge. Picture on left was taken on October 15, 2012, and the picture on the right was taken on August 14, 2012.


Figure 198. Drilling rig drilling on an island capped by Glendon Limestone in the Mississippi River at Pier E-1 of the Interstate 20 bridge at Vicksburg. At left, the Glendon Limestone plunges below the river level on the south end of an anticline. At right, the vertical pipe behind the rig contains a tiltmeter that measures lateral movement below ground. Pictures were taken on October 15, 2012.

capped by 15 feet of Glendon Limestone. The picture is a view of the anticline from the southern side. The top ledge of limestone on the island is roughly the top ledge of limestone in the river bank. Low water has afforded the opportunity to drill this island for information concerning possible shear surfaces associated with movement on Pier E-1. The rock comprising the island has moved laterally to the west and is some 15 feet lower than the rock in the neighboring river bank. Drilling on the island began on Monday, October 15 and continued to October 22, 2012. Oriented Shelby tube samples (samples that could reveal shear planes) were taken at five-foot intervals and shipped to a laboratory for examination. The goal of this study is to find a way to stop the formation and the Interstate 20 bridge piers from moving.

Figure 188 shows the drilling rig on the island. At left in the figure, the drilling rig is shown from the view of the jack-up barge anchored next to the island. The Glendon Limestone can be seen plunging below water level on the south end of the anticline. At right in the figure, a large vertical metal pipe stands above a platform of rip-rap behind the drilling rig. Men are standing around an opening in the base of the pipe in which a ladder leads to an instrument called a tiltmeter. The tiltmeter records subsurface movement along shear planes. Movement of less than an inch has been recorded over the last several years at a depth of 120 feet.

An Associated Press release posted September 5, 2013, stated that the U.S. Department of Transportation announced Tuesday (same date) that a grant of $4.25 million in federal money would be given to Mississippi officials to repair the Interstate 20 bridge over the Mississippi River at Vicksburg. The release cited a May 2006 study that found the piers on the I-20 bridge were shifting along with the earth surrounding them. The money would be used to strengthen the bridge so its truss and deck could withstand the side-to-side movements of the piers. The money would also go to bolster monitoring systems. The release noted that the four-lane bridge was built in 1972 and was flanked by a 1930 railroad bridge whose road deck had been closed.

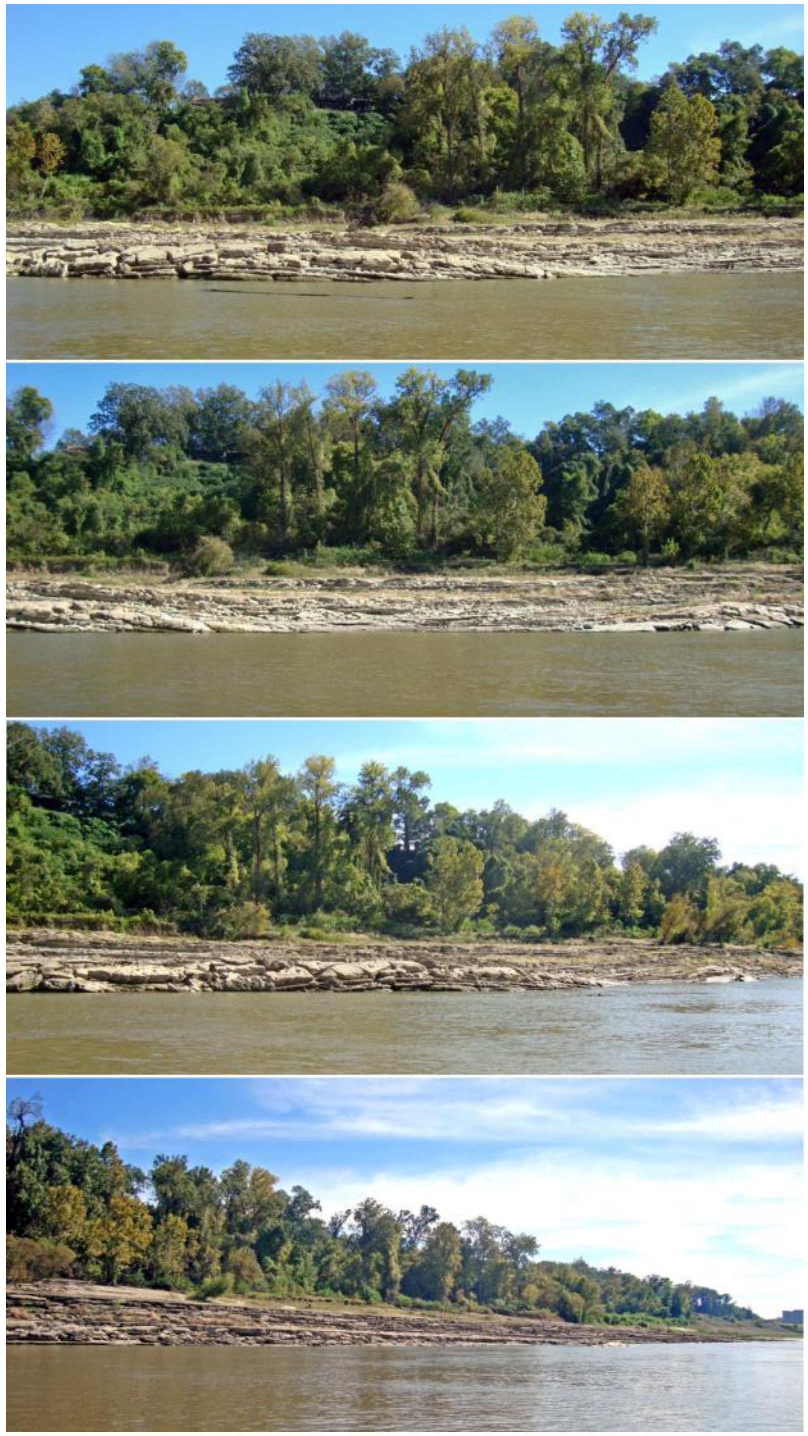


Figure 199. Structure in the Glendon Limestone along the east bank of the Mississippi River at Vicksburg. Pictures were taken on October 15, 2012.

Figure 189 shows geological structures in the Glendon Limestone south of the Interstate 20 bridge. From top to bottom, these structures include: (1) an anticline, with limestone layers cresting above river level, (2) a syncline between two anticlines, with limestone layers sagging below river level, (3) an oblique view of a rising anticline and sagging syncline, and (4) a monoclinal southward dip of limestone strata, sloped like a boat ramp into the river. The latter is the last appearance of the Glendon Limestone along the Mississippi River before it dips beneath younger strata in the southern part of Mississippi. Going north from this southern-most river exposure, the Glendon Limestone makes a gentle rise to exposures in the road cuts along Business Highway 61 in north Vicksburg south of the Vicksburg National Military Park. Further north, the Glendon Limestone was once quarried in the hills along Highway 3 north of Redwood for the manufacture of Portland cement.

Figure 200. Slope repair on the steep-sided hills in the battle fields of Vicksburg National Military Park. Picture (digital; Image 1929) was taken on April 14, 2010.

Figure 201. Slope repair on a steep hillside at the marker for Ewing's Approach, which extended from the marker along graveyard road to the distant hillside. Picture (digital; Image 1930) was taken on April 14, 2010.

Figure 202. Remnants of an old trench in loess in the Vicksburg National Military Park. Picture (digital; Image 1931) was taken on April 14, 2010.

Figure 203. National Park Service personnel view slope repairs in the distance at the Vicksburg National Military Park. Picture (digital; Image 1932) was taken on April, 2010.

Vicksburg National Military Park. Morse (1935c) published a short text on the geology of the Vicksburg National Military Park area, including a "Map of the Siege of Vicksburg" (with illustrated relief) as it was in August 20, 1863. Concerning the trench warfare at Vicksburg, Morse stated that the loess was "the most ideal of mantle rock for rapidity in excavation and for stability of vertical walls." Both Confederate and Union forces entrenched in the loess, the Confederate trench "encircling the city [Vicksburg] from bluff almost to bluff with a topographically unbroken trench, save for the crossing of Glass Bayou at Jackson Road." The Union Army dug a parallel trench for approximately two-thirds of the length of the line of defense trenches with only three transverse ridges connecting the opposing trenches: the Graveyard Road ridge, the Jackson Road ridge, and the Baldwin Road ridge. Elsewhere, steep valleys separated the trenches. Morse concluded that "the angularity of the valleys in the loess-covered region absolutely controlled the disposition of these two great armies."

Myers et al. (2005) discussed the impact of the Vicksburg loess on the 1863 siege of Vicksburg (**figures 200-203**). Positive impacts for the defenders included; (1) defendable fortifications for both soldiers and civilians, (2) good observation points from the loess hill tops, and (3) a soil that allowed the construction of tunnels and caves as safe places from exploding shells. Negative impacts include: (1) the ability of Union forces to

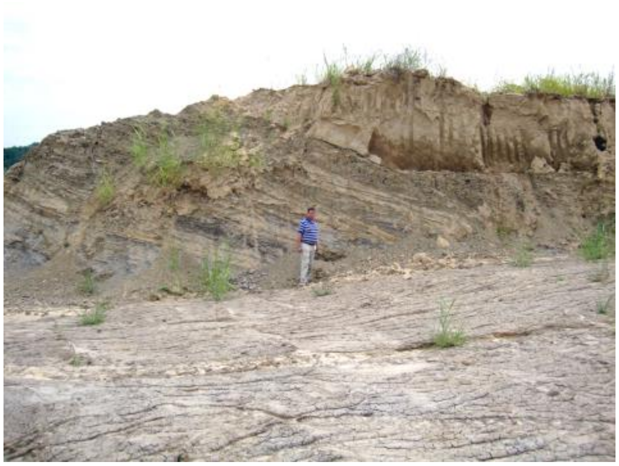


Figure 204. James Starnes standing in from of tilted strata in the Bucatunna Formation rotated in a slump block along the bluff line of the Loess Hills at Keyes Scrap Metal on Highway 61 in north Vicksburg, Mississippi. Picture (digital; Image 1938) was taken on August 24, 2011.

Figure 205. Above the slumped and tilted beds of the Bucatunna Formation at Keyes Scrap Metal on Highway 61 at Vicksburg is the fault shear plane of an overlying slump block containing loess in sharp contact with the underlying stratified clay. Picture (digital: Image 1941) was taken on August 24, 2011.

Figure 206. Shear plane between two slump blocks at Keyes Scrap Metal on Highway 61 at Vicksburg, Mississippi. The lower slump block contains Bucatunna Clay; the upper slump block contains loess. The pre-loess gravel is missing in this section. Picture (digital; Image 1939) was taken on August 24, 2011.

Figure 207. James Starnes pointing to a slump fault with loess down to the left and pre-loess sand and gravel with overlying loess in place to the right at Keyes Scrap Metal on Highway 61 at Vicksburg, Mississippi. Picture (digital; Image 1940) was taken on August 24, 2011.

tunnel under defenses and set off explosives, (2) the breakdown of the loess to fine dust that caked clothing and equipment, and (3) hydrologic properties that contributed to the shortage of water within the city, which contributed to the outbreak of disease and the inability to treat wounded soldiers.

Ancient Slope Failures North of the Vicksburg Military Park. Excavations at Keyes Scrap Metal on Highway 61 Business in north Vicksburg, Mississippi, cut into old slumps in the loess and pre-loess strata as well as into the underlying bedrock of the Bucatunna Formation. These slumps occurred along the bluff line of the Loess Hills where they meet the Mississippi River Alluvial Plain. **Figure 204** shows a rotated slump block with tilted beds of the Bucatunna Formation. **Figures 205 and 206** show the shear plane of a second overlying slump block, where loess is in sharp contact with the Bucatunna Formation and the pre-loess gravel is missing. A normal section of Bucatunna, pre-loess gravel, and loess is present in an adjacent excavation-cut exposure. **Figure 207** shows a slump fault with a slumped block of loess to the left against a normal section of pre-loess

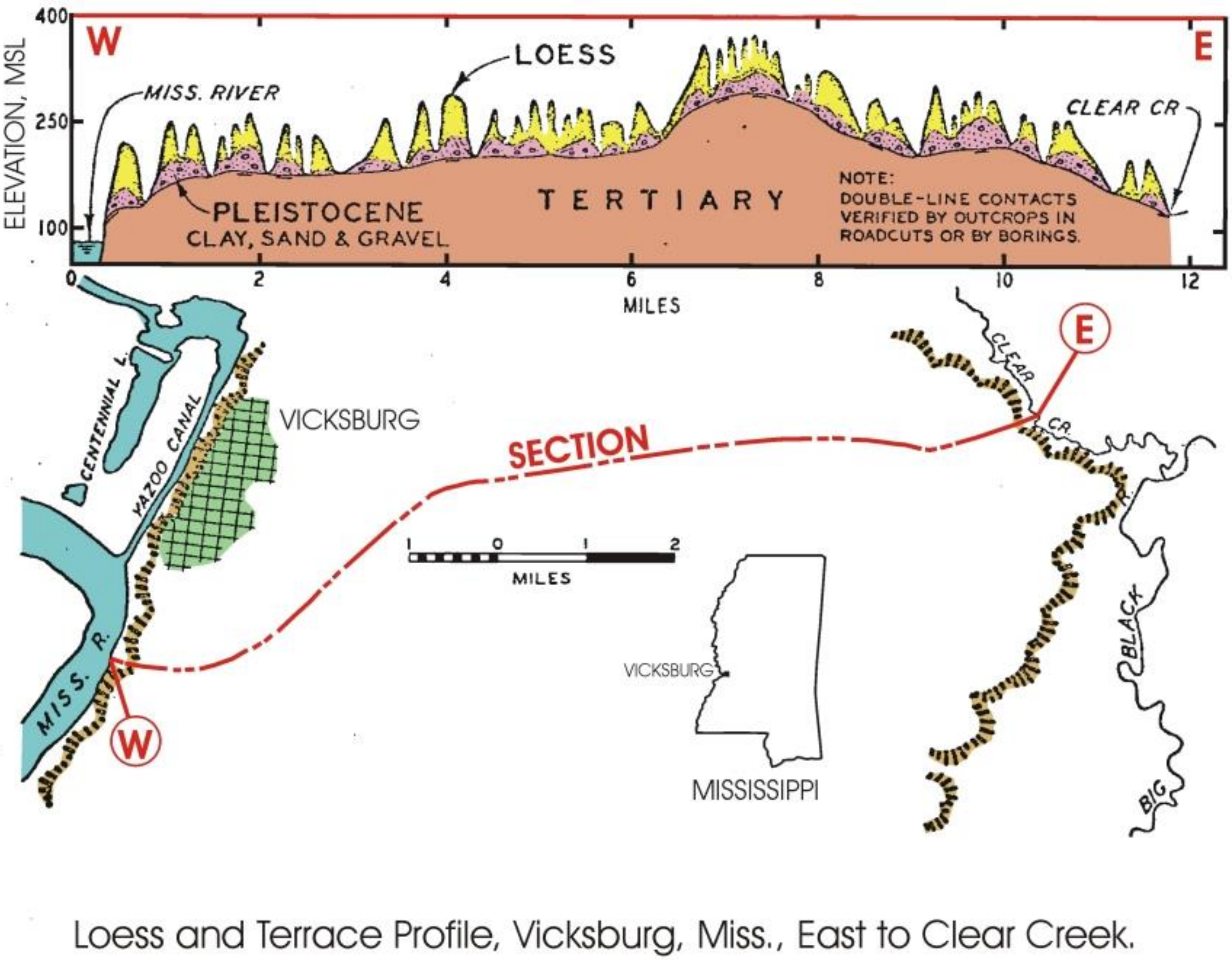


Figure 208. Profile of pre-loess terrace deposits and loess along Interstate 20 from the bluff line on the Mississippi River at Vicksburg to the bluff line on Clear Creek in central Warren County. This profile is based on a detailed profile made by the Mississippi State Highway Department from road cuts and borings. Picture (Image 2099) is from Kolb et al., 1976, p. B-5.

overlying loess in place to the right. Even though the pre-loess gravel has a rough texture, the contact along the shear plane with the loess is amazingly sharp and regular. An in-place sequence of pre-loess gravel and loess was present out of view to the left side of the photograph in **Figure 207**.

Figure 208 is a profile constructed by the Mississippi State Highway Department along Interstate 20 in western Warren County, which shows the distribution of pre-loess terrace deposits and the overlying loess. The pre-loess terrace deposits are ancient alluvial fill deposits of the Mississippi River when it flowed at a higher elevation and to the east of its present-day course. This alluvial fill was truncated by erosion into hills and valleys before the deposition of thick loess deposits of Peorian Loess age. Radiocarbon dates determined from fossil land snail shells in this loess place its age as between 25,000 and 18,000 years old. The thickest deposits of loess along the profile cap the highest pre-loess hilltops.

Gravel Pit Landslides. Water saturation lowers the strength and cohesion of soil and can destabilize pit high walls. Slope failure associated fatalities are a matter of being at the wrong place at the wrong time. On June 3, 2016, a landslide in a high wall separating water-filled pits at the Green Brothers Gravel Company Inc. Harmony Mine and Mill's Johnson Pit in Crystal Springs, Mississippi, buried two workers operating heavy equipment under a sludge of wet sand (**figures 209-210**). Rain hampered recovery efforts for workers Emmitt Shorter and James Dee Hemphill. It was eight days before both bodies were found. Mine Safety and Health Administration officials reported that the tragedy began when a pond dam above the gravel pit broke, sending water and mud onto Shorter and Hemphill. The miners were working in a pit adjacent on old pit holding waste clay and sand placed there for reclamations purposes. An abandoned roadway embankment, which partially bound the old pit, failed spilling tailings and slurry into the working pit (**Figure 211**). The Mine Safety and Health Administration (MSHA) classified the accident as the 1st and 2nd inundation accidents in 2016.

According to the MSHA Report of Investigation MAI-2016-07/8, Hemphill was loading Shorter about 50 feet west of the Johnson Pit wall, while Shontavius Noral was parked west of the loading operation, waiting to be loaded in his truck. "Norals observed the east wall of the Johnson Pit begin to break and slurry and tailings (waste sand and clay) material breach the wall. He shifted his truck into reverse and backed up the bank on the west side of the pit, before shifting into a forward gear to exit the pit, as the material engulfed the excavator and haul truck that Hemphill and Shorter were operating. Norals stated that the entire incident occurred in a matter of seconds."

Figure 209. Failed high wall between the Johnson Pit at lower left and the Ball Pit at upper right from MSHA Report MAI-2016-7/8. Image 2521.

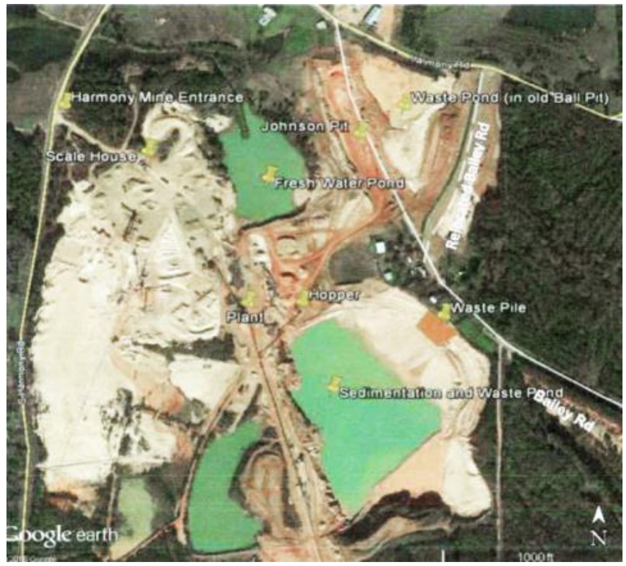


Figure 210. Overview of Harmony Mine Layout shown on a satellite image dated December 14, 2015, viewed in Google Earth from MSHA Report MAI-2016-7/8. Image 2522.

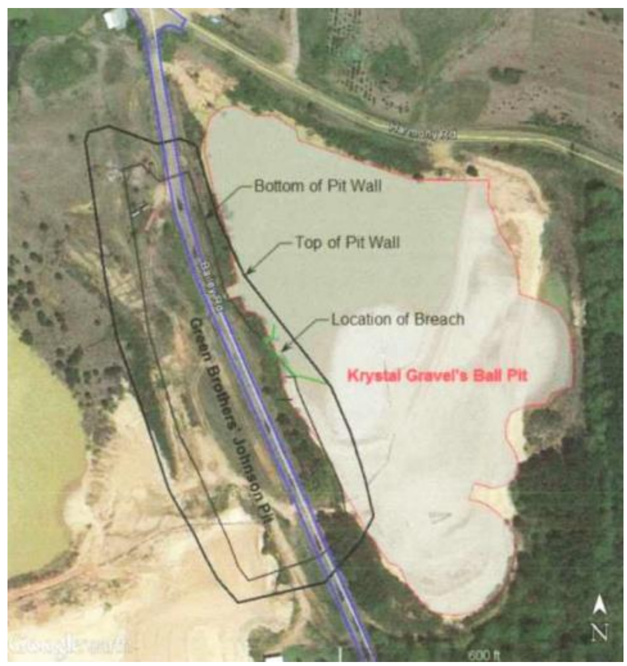


Figure 211. Outlines of the original Ball Pit in relationship to the mining of the Johnson Pit. The area of the Johnson Pit widens where the wall material composition transitions from primarily sand and gravel to primarily tailings. The excavator and haul truck were both on the pit bottom near the location of the failure. Picture and text from MSHA Report MAI-2016-7/8. Image 2523.

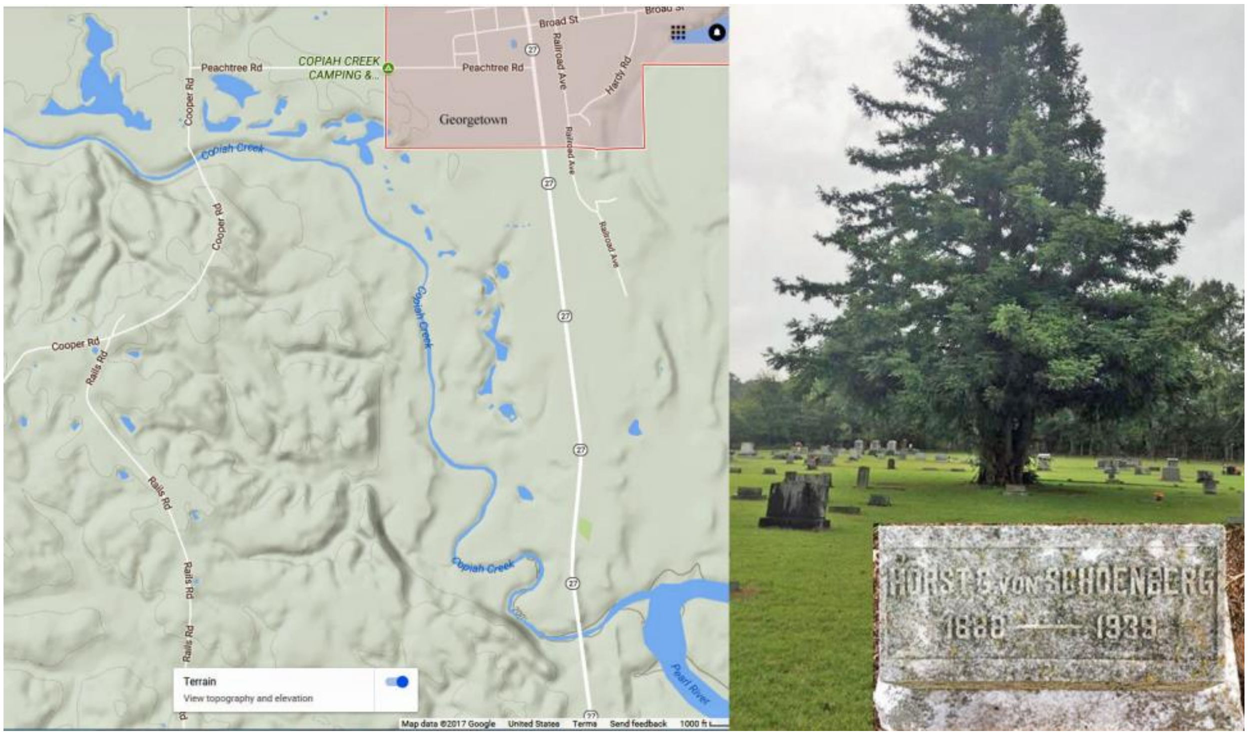


Figure 212. Left, areal terrain view of Copiah Creek south of Georgetown in Copiah County, Mississippi. The lakes on the creek's eastern floodplain are remnants of dredge ponds created by Schoenberg and Green Brothers for the purpose of gravel excavation. Right, tree in Georgetown cemetery planted in honor of Schoenberg and an enlargement of his gravestone; the actual stone is in front of the tree above the enlargement. Picture at right were taken by Will Lowery on July 18, 2017. Image 2524.

The Executive Director of the Mississippi Emergency Management Agency characterized the accident stating, "In the history of mining and quarry operations in the United States, this is an unprecedented event." While the situation at the Crystal Springs gravel pit may be unique, there have be other fatalities due to landslides of gravel pit high walls in Mississippi. In fact, the Green bothers bought their original gravel operation in Mississippi from the widow of a man killed in a wall failure. According to Will Lowery who grew up in Georgtown in the 1930s, Horst G. von Schoenberg owned a gravel dredge operation along Copiah Creek in Copiah County. He pumped water from the creek to fill his dredge pit in the alluvial gravels along the creek bank. Lowry had relatives who worked at the pit, including Eulou Lowery and several members of the Errington and Powell families.

Schoenberg was born in Germany (Saxony) on January 11, 1888, served two years as a corporal in a German artillery unit, and immigrated to America on April 19,1914, before the assassination of Archduke Franz Ferdinand on June 28, 1914, and before Germany declared war on France on August 3, 1914. He married Martha Wendel in New Orleans on July 18, 1914, both at age 26. Wendel was born in Cassel, Germany, and immigrated from the German port of Bremen, arriving in America on July 9, 1914. Shoenberg's U.S. draft registration card date June 5, 1917, placed him and his wife in Tangipahoa, Louisiana.

The Shoenberg gravel operation started in the Copiah Creek floodplain about half a mile upstream from the confluence of Copiah Creek and the Pearl River and worked upstream for about two or three miles (**Figure 212**). The pit had a floating dredge that pumped water, sand, and gravel up to a washing tower. Workers were transported to the dredge in a flat-bottom boat with a cork bottom and side railing made of two-by-fours. They used a pole to push the boat back and forth. The dredge floated on a platform built on barrels. The dredge pipe was also floated on platforms built on barrels. The mine had a rail spur and sold gravel by the train-car load as well as locally. Lowery remembered a man bringing his trailer to buy a load of gravel. As the gravel was being loaded, the trailer's tires blew out under the weight.

The Shoenbergs lived a frugal life for people with such a substantial business. Attorney William E. Spell Sr., now from Clinton,


Figure 213. Our sources on gravel pit landslide fatalities, Will Lowery (left) and Herb Guthrie. What are the chances that two men eating breakfast at McDonald's in Clinton, Mississippi, would both know people killed in gravel pit landslides? Picture was taken on June 2, 2017. Image 2526.

Mississippi, remembered Shoenberg walking past his Georgetown home everyday on his way to the gravel mine. The Shoenbergs used their car on Sundays to attend the Lutheran Church in Jackson.

Shoenberg was killed in 1939 when a bank he was standing on above the dredge pond caved in, and he was crushed in the collapse. The accident occurred on May 12, and he died on May 14. The death certificate gave the immediate cause of death as shock, retroperitoneal hemorrhage from comminuted fractured pelvis, and skull fracture/concussion. The cause of death was listed as "fall." After the death of Shoenberg, the Green brothers from Franklinton, Louisiana, bought the gravel company from his widow, who lived in a single room apartment in the home of Dr. Chapman in Georgetown (Will Lowery visited her there at times). When gravel resources were exhausted on Copiah Creek, the operation was moved to Harmony Road just outside of Crystal Springs. (Will Lowery, personal communication, 12-30-2016; **Figure 213**).

The MSHA report on the Green Brothers Company accident (2016) included a list of five Best Practices to prevent that type of accident. One listed practice was: "Embankments adjoining workplaces and travelways should be examined weekly, or more often, if changing ground conditions warrant." However, such examinations themselves can be a source of great danger. Herb Guthrie, who grew up in Yazoo County, Mississippi, lost an uncle to a gravel pit high wall collapse at Midway. His uncle Warren Clifton (Buddy) Guthrie and county road foreman John O. Guion were in the bottom of a gravel pit examining the wall on October 4, 1951, when one side of the pit caved in pinning both men under several feet of gravel (Herb Guthrie, personal communication, 1-2-2017).

The Thursday October 11, 1951, edition of *The Yazoo City Herald* gave the following account under the front-page heading: *Cave-In Snuffs Lives J. O. Guion, W. C. Guthrie Last Thursday Afternoon.* "Suffocation from being buried alive was the tragic fate of two Benton residents, John O. Guion, aged 49, and Warren Clifford Guthrie, aged 42. Both men serving as road foremen for Yazoo County Roads were killed when the bank of a gravel pit caved in.

"The pit located on the P. S. Carley road about six miles east of Yazoo City and just off the main highway to Jackson, apparently caved in shortly after the men reached the floor of the pit. The pit which is 20-foot-deep has just been put in use as a source of gravel for the maintenance of the county's secondary roads.

"According to Joe Shepherd, county road superintendent, both bodies were erect when found beneath four feet of gravel. This indicated that they were standing at the bottom of the pit when the cave-in occurred.

"Motors of the bulldozer and the pick-up truck that the dead men had around were still running when the families first reached the pit about dusk. The bodies however were not recovered until 11 p.m. They were taken to the Stricklin-King Funeral Home."

CHAPTER 5. FOUNDATION FAILURES

THE GLENDON REGOLITH AND THE NEW BRANDON HIGH SCHOOL

From the September 2009 issue of *Environmental News*, Dockery, 2009, p. 29-30.

The *Rankin County News* published an article on page 3A of its Wednesday, January 21, 2004, edition with the headline "Yazoo Clay Found on Brandon High School Site." This news added another element to the controversy over the school board's selected site for the new high school. An issue of concern from a geologic standpoint was that the swelling clay found at the site could not have been the Yazoo Clay. The geologic map in the Rankin County geology bulletin published in 1971 showed the higher elevations of the site to be on the limestone of the Vicksburg Group and the lower elevations to be on the sands and clays of the Forest Hill Formation. The top of the Yazoo Clay was more than a hundred feet below the site. Oddly enough, one reason given for rejecting an alternative site was that the site was underlain by limestone. A few soil borings had been made at the new site, but only in the lower elevations (in the Forest Hill Formation). Additional borings recommended by the engineering firm were not made.

Prompted by the newspaper article, Steve Jennings, a Rankin County resident who worked for the Office of Land and Water Resources at the time, invited me to go with him to see the bedrock geology of the new Brandon High School construction site. We visited the site on January 28, 2004, and found boulders of the Glendon Limestone (the upper limestone of the Vicksburg Group) along the roadside. These boulders had been moved during the site preparations made by the previous owner. In walking over the graded site surface, areas of lighter colored soil indicated the presence of limestone pinnacles below. The site was underlain by karst remnants of limestone surrounded by a matrix of expansive residual clay. Similar occurrences of weathered Glendon Limestone were known in the Brandon area and elsewhere in Rankin and Hinds counties.

Regolith is the geologic term for the weathered bedrock beneath the soil horizon. The Glendon Limestone and its associated regolith are present across the formation's outcrop belt in Mississippi from Vicksburg to north of Waynesboro, and from there continuing across Alabama into the panhandle of Florida. Locally, expansive clays of this regolith may cause foundation problems. A variety of expansive clay called bentonite was mined from the Glendon Limestone in Smith County for many years.

During our visit to the high school site, Steve Jennings asked a trackhoe operator to dig beneath an area that appeared to be weathered limestone. A large mass of Glendon Limestone was found just below the surface (**figures 214-215**). Eventually, the Glendon

Figure 214. A backhoe excavates pinnacles of limestone, at the request of MDEQ geologists, from swelling clays in the Glendon regolith under the graded foundation for the new Brandon High School. This soil proved unsuitable as foundation material and was removed at a considerable cost overrun. Picture (digital, CD 44: Image 999) was taken by Stephen Jennings on January 28, 2004.

Figure 215. Backhoe-excavated limestone pinnacle from the swelling clays of the Glendon regolith under the graded foundation for the new Brandon High School. Picture (digital, CD 44; Image 1000) was taken by Stephen Jennings on January 28, 2004.

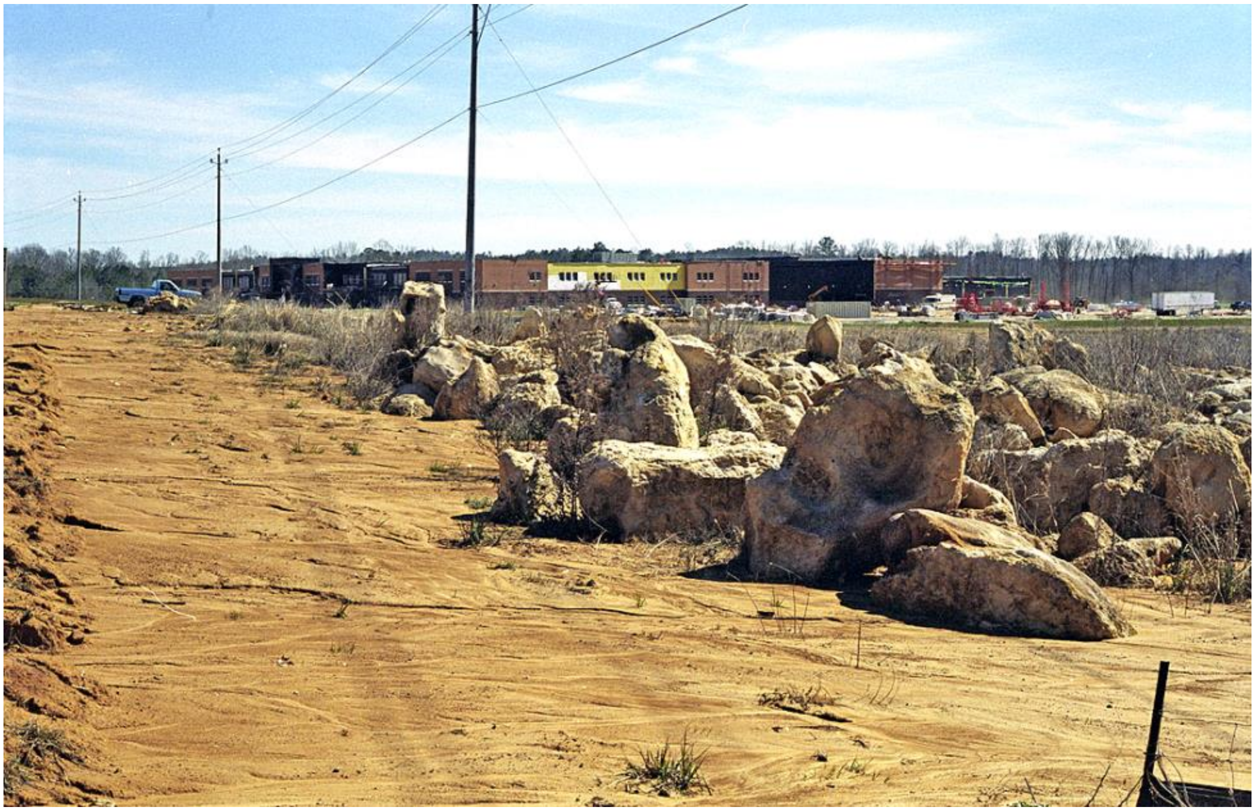


Figure 216. Boulders of Glendon Limestone excavated from the site of the new Brandon High School where foundation problems were found associated with the weathered limestone. Picture (color negative 540-23A; Image 332) was taken on March 8, 2005.

Figure 217. Hinds Community College (Rankin County Campus) Physcial Geology Class (fall semester 2009) on a field trip to an exposure of the Marianna Limestone and overlying Glendon Limestone on Highway 18 about 3.5 miles west of the Brancon High School. Picture (digital, CD 61; Image 1283) was taken on August 25, 2009.

regolith layer had to be removed from the site and replaced with suitable foundation material at a cost overrun estimated at four million dollars. The cost of the Rankin County geology bulletin, along with its geologic map, was just three dollars. Though this bulletin is now out of print, it can be viewed for free at the MDEQ library. **Figure 216** shows a field of limestone boulders, which had to be removed from beneath the High School foundation before the school could be built. **Figure 217** is a picture of the Hinds Community College (Rankin County Campus) Physical Geology Class (fall of 2009) on a field trip to an outcrop of the Marianna Limestone and overlying Glendon Limestone on Highway 18 about 3.5 miles west of Brandon High School.

BUILDING A HOUSE ON THE YAZOO CLAY

The best example have of a house correctly built on Yazoo Clay is the house I (Dockery) grew up in on 4550 Manila Drive in Jackson, Mississippi. This lot was part of a GI subdivision owned by the State of Mississippi. In 1948, the State Building Commission held a lottery for soldiers coming home from World War II. On the day of the lottery, there was a box with the names of returning GIs and another box with a lot number of some 400 lots. The GI lots were surveyed, furnished with roads and utilities, and were ready for building. When my father's (David T. Dockery, Jr.) name was pulled, the lot pulled from the other box was on Normandy Drive. He, as did the others, had one month to decided whether to buy the lot or turn it down.

At the time, my father worked for Contractor's Material Company and thus knew good building contractors, one of which he hired to oversee the building of his house. When the contractor drilled on the Normandy lot for the foundation piles, the drill hit water at six feet. The drill rig operator told my father to turn the lot down. My father then contacted the State Building Commission and set up an appointment to discuss the matter. At the time of the appointment, he met with the director of the State Building Commission at the Capitol Building in the presence of Governor Hugh White. When my father asked to exchange his lot, the governor asked the director, "What does the boy want?" My father told the governor about drilling into water on the Normandy Street lot and that drill-rig operator recommended that he not build on it. The governor asked the director, "Are there any more lots?" The director said that there were more lots. The governor responded, "Let him pick out the lot he wants and pay the difference, if there's a difference." My father then chose the lot at 4550 Manila Drive.

As was probably true for all lots in the GI subdivision, the Manila Drive lot rested on weathered Yazoo Clay. The building contractor drilled 18 boreholes for pilings to a depth of 20 feet (a depth necessary to penetrate the weathered expansive clay to the blue-gray stiff unweathered clay). The holes were filed with reinforcing steel and concrete and served as foundation piers for the house. Then the contractor poured a concrete skirt foundation for the house perimeter. The wooden floor and superstructure were built on the concrete skirt and pilings. A crawl space between the floor and the ground provided room for the Yazoo Clay to rise and fall with the wetting and drying of the soil. We never had any foundation problems with this house (**Figure 218**).

Building practices have regressed since the time my father built his house. Constructing piers under a residential building is considered too costly. Now houses are commonly built on a slab foundation constructed on compacted fill dirt. Once the slab tilts and buckles under the pressure of the shifting clay below the fill, then a foundation contractor is hired to dig beneath the slab and install concrete and steel piers at a much greater expense than if the house had been built on concrete piers to start with or had a sufficient buffer of fill material. This process often has to be repeated multiple times as the slab continues to move on the expansive clay.

How much is enough fill under a conventional concrete slab foundation? According to Tommy Dunlap of Burns Cooley Dennis, Inc., five-foot fill buffers were assumed to be adequate prior to 1980. However, due to some unacceptable foundation movements that occasionally occurred, the buffer recommendation was increased to seven feet—mostly for litigious reasons. Seven feet of fill buffer is also recommended for post-tension slabs. The thicker the buffer, the less the risk of foundation movement but the greater the cost. The Nissan Plant, built on the Yazoo Clay in Madison County, wanted minimal risk as did the State of Mississippi, which supplied a warranty on the plant, so extra expense was used to provide a ten-foot buffer of fill. After the loess-type fill was added for the Nissan foundation, the fill was treated with a layer of lime to remove the excess moisture content.

Stories of expensive foundation repairs for homes situated on the Yazoo Clay span the Jackson Metro area from the eastern half of Clinton to the Ross Barnett Reservoir and Pelahatchie Bay area of Rankin County. One resident in the Bellegrove neighborhood of the reservoir area said that most houses on his street have had foundation repairs. In Clinton, Mississippi, as shown in the cross section in **Figure 219** and on the geologic map for the Clinton Quadrangle in **Figure 220**, the problem of the shifting Yazoo Clay can be avoided by building in the western half of the city where the bedrock consists of the Forest Hill Formation and other geologic units. The Jackson Quadrangle geologic map (**Figure 221**) on the next page shows that most of the Jackson area rests above the Yazoo Clay.

Figure 218. Dockery home at 4550 Manila Drive built in a GI subdivision in north Jackson in 1949 on a foundation of eighteen 20-foot-deep piers and a poured concrete perimeter skirt. At left is the garage (converted to a room) on slab; at right is the L-shaped house on piers. Picture (slide; Image 1935) was taken in March of 1974.

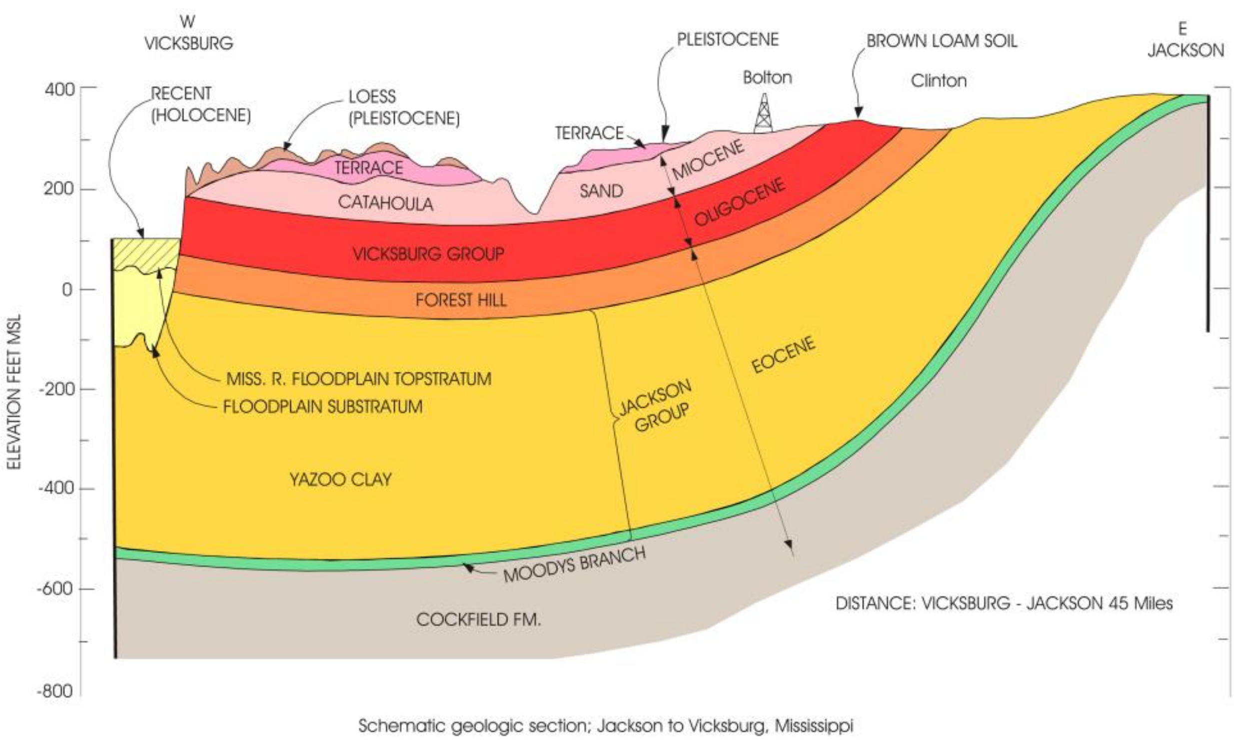


Figure 219. Cross section from Vicksburg to Jackson, Mississippi, showing the outcrop of the Yazoo Clay on the western flank of the Jackson Dome. The western side of Clinton is not on the Yazoo Clay outcrop belt. Picture (digital, Image 2098) is modified from Kolb et al., 1976.

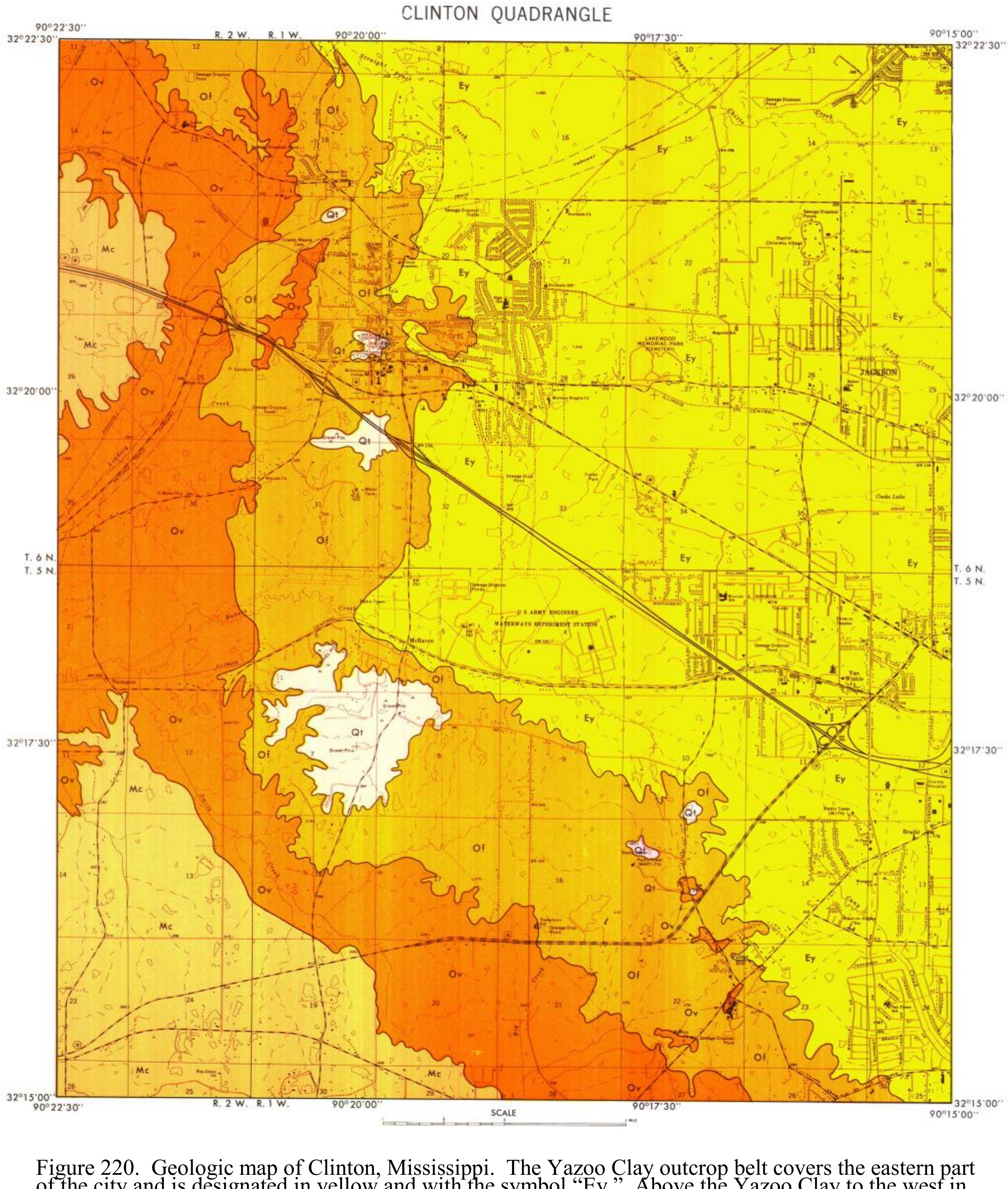


Figure 220. Geologic map of Clinton, Mississippi. The Yazoo Clay outcrop belt covers the eastern part of the city and is designated in yellow and with the symbol "Ey." Above the Yazoo Clay to the west in light orange with the symbol "Of" is the Forest Hill Formation. On this outcrop belt in pink are fluvial terrace sand deposits that underlie the highest elevations. West of the Forest Hill outcrop in dark orange with the symbol "Ov" is the Vicksburg Group, which contains limestone. In the upper left (west) with the symbol "Mc" is the Catahoula Formation. Image 1933 from: Green, J. W., and M. Bograd, 1973, Environmental Geology of the Pocahontas, Clinton, Raymond, and Brownsville Quadrangles Hinds County, Mississippi, Environmental Geology Series no. 1: Mississippi Geological Survey, p. 17.

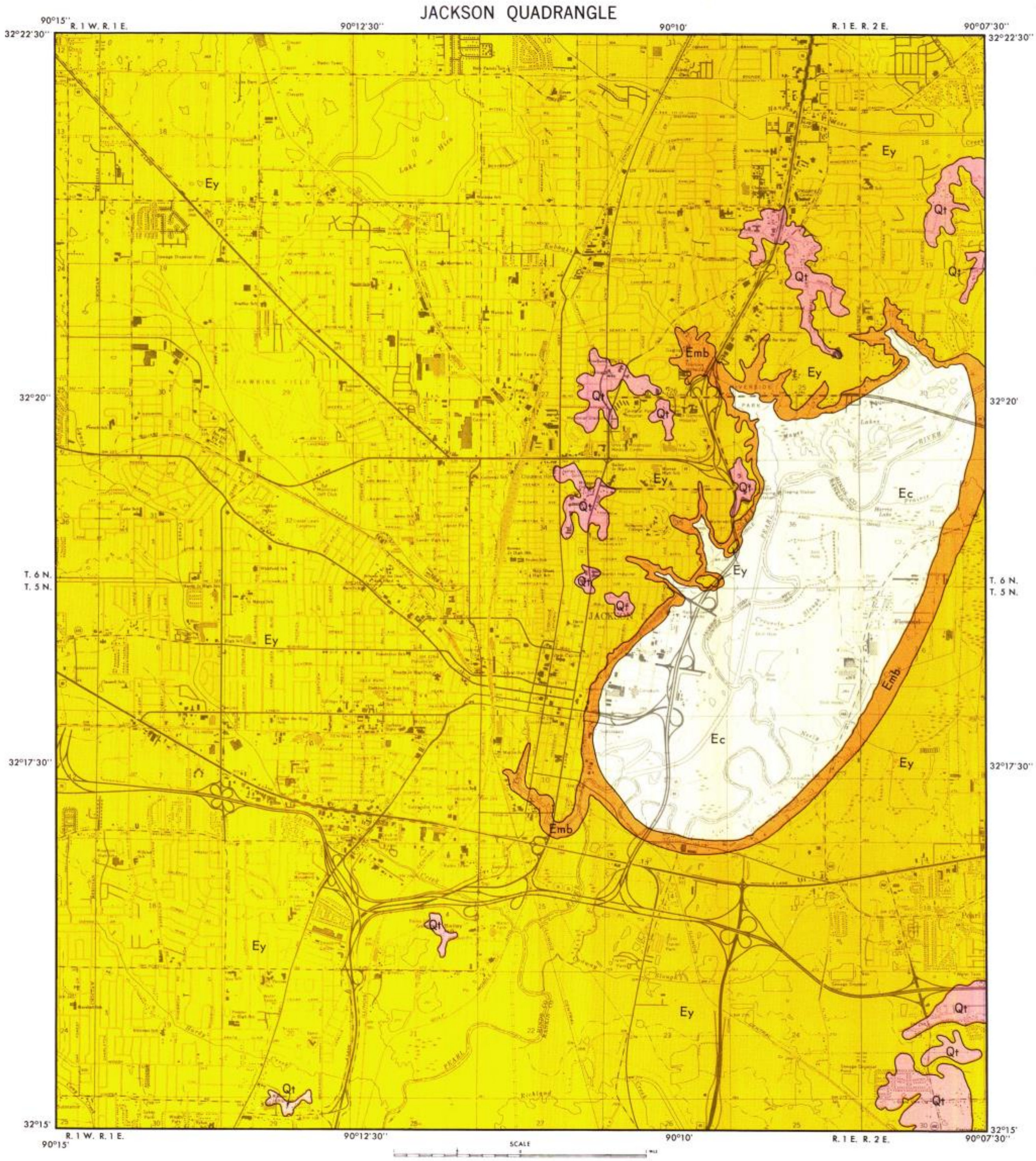


Figure 221. The geologic map of the Jackson Quadrangle is an eastward extension of the map in the facing figure. The majority of the Jackson Quadrangle consists of soil overlying Yazoo Clay (Ey). Some terrace sand deposits in pink (Qt) provide a buffer above the Yazoo Clay. In the lower reaches of creeks flowing into the Pearl River and beneath the Pearl River alluvium, is an orange ring with a central white oval. These are, respectively, the Moodys Branch (Emb) and Cockfield (Ec) formations, which underlie the Yazoo Clay and outcrop on the crest of the Jackson Dome where the Yazoo Clay has been eroded away. While these formations contain good foundation material, their outcrop belts are in flood prone areas and are mostly covered by Pearl River alluvium. Image 1936 from: Green, J. W., and S. C. Childress, 1974, Environmental Geology of the Madison, Ridgeland, Jackson, and Jackson SE Quadrangles Hinds, Madison, and Rankin counties, Mississippi, Environmental Geology Series no. 2: Mississippi Geological Survey, p. 16.

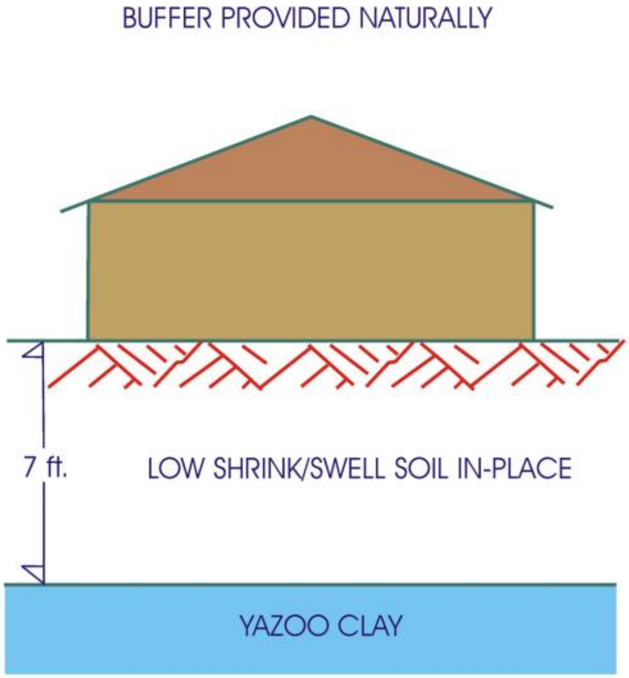


Figure 222. House with a slab foundation built above a naturally occurring 7-foot thick low shrink-swell soil in place overlying the Yazoo Clay. Image 1936, modified from Tommy Dunlap's slide presentation.

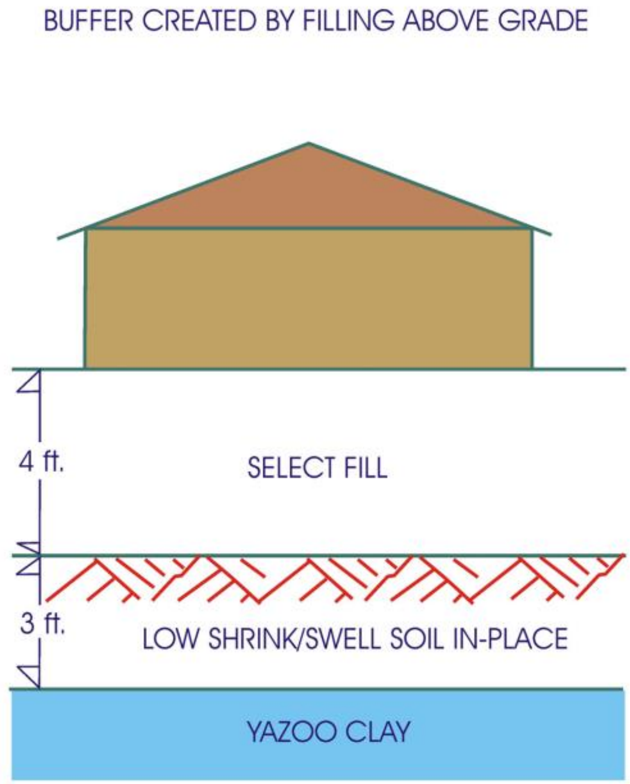


Figure 223. House with a slab foundation built above 4 feet of select fill added above grade on a 3-foot naturally-occurring layer of low shrink-swell soil overlying the Yazoo Clay. Image 1937, modified from Tommy Dunlap's slide presentation.

Figures 222-227 are from a Continuing Education for Design Professionals PowerPoint Presentation by Tommy Dunlap of Burns Cooley Dennis, Inc. They show the natural or constructed buffer required above the Yazoo Clay to prevent or sufficiently retard foundation damage to a slab on grade. **Figure 222** shows construction on natural grade with a 7-foot-thick natural buffer above the Yazoo Clay. **Figure 223** shows the addition of 4 feet of select fill above natural grade in which a 3-foot buffer of low shrink-swell soil is in place. **Figure 224** shows a 7-foot-deep excavation of Yazoo Clay with the clay replaced by a compacted select backfill, which extends 7 feet away from the slab margin. Figure 184 shows a 4-foot-deep undercut and select backfill with a 3-foot-thick select backfill above grade, both extending 7 feet from the slab margin. In **figures 224 and 225**, the fill buffer requires a lower plasticity clay with a liquid limit no greater than 45% and with the exclusion of higher permeability sands. The lower permeability of this clay, along with normal evaporation and transpiration, prevent an excessive wetting front from moving downward and filling the back fill up like a bathtub. Water saturation decreases the strength and cohesion of the fill. If a more porous fill material is used, the installation of a French drain and dry pump may be needed around the perimeter of the foundation to remove the excess water. **Figure 226** shows a house built on piers with the correct drainage around the foundation. **Figure 227** shows the correct distance for a tree from the house foundation to prevent clay soil shrinkage at the site. That distance is equal to the height of the tree.

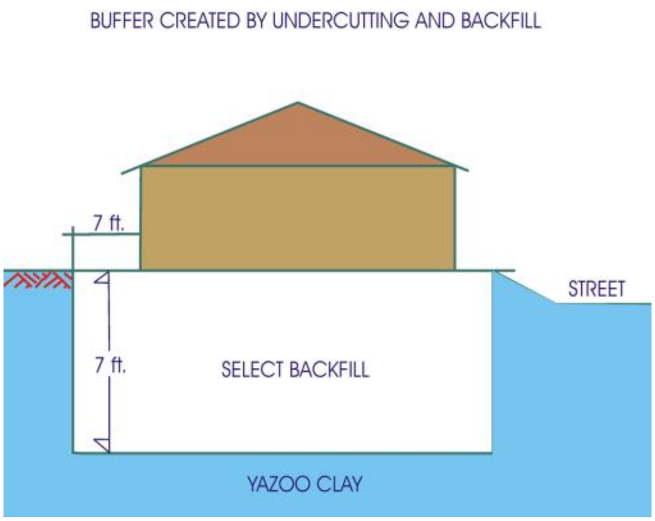


Figure 224. Foundation where a 7-foot-thick section of Yazoo clay has been excavated and replaced with 7 feet of compacted select backfill. The excavation and backfill extend 7 feet laterally from the edge of the slab foundation. Specifications for the fill in this foundation require a low plasticity clay with a liquid limit no greater than 45% to prevent the fill from becoming water saturated. Image 1945, modified from Tommy Dunlap's slide presentation.

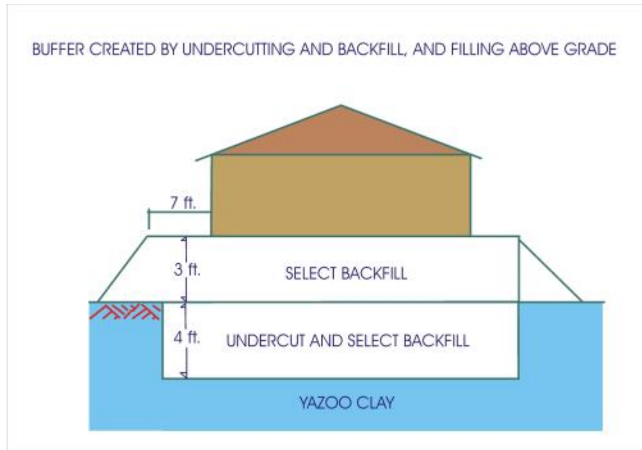


Figure 225. Foundation where a 4-foot-thick section of Yazoo Clay has been excavated and replaced with 7 feet of compacted backfill. Above this a 3-foot-thick section of compacted select fill is added above grade. Both the fill below and above grade extends 7 feet laterally from the slab foundation. Specifications for the fill in this foundation require a low plasticity clay with a liquid limit no greater than 45% to prevent the fill from becoming water saturated. Image 1946, modified from Tommy Dunlap's slide presentation.

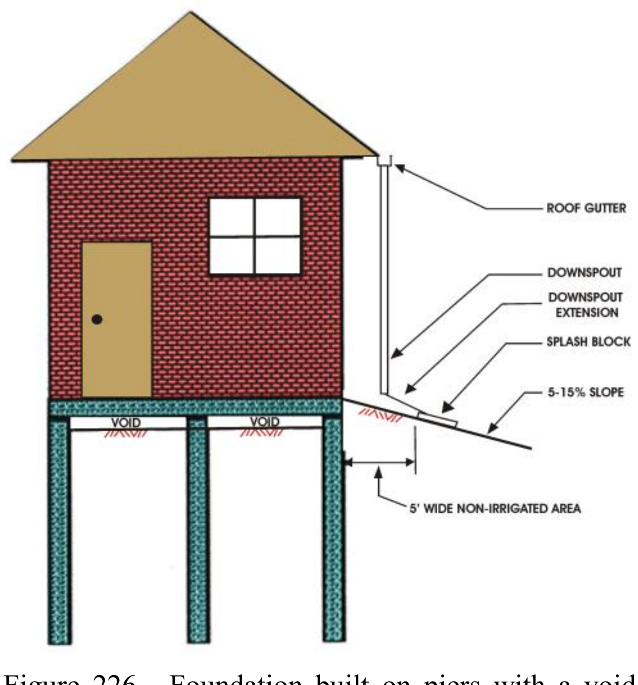


Figure 226. Foundation built on piers with a void space between the ground and floor. To keep the foundation well drained, a grade of 5 to 15% is built around the foundation perimeter, and gutters extend five feet from the building to provided a five-foot wide non-irrigated area. Image 1958, modified from Tommy Dunlap's slide presentation.

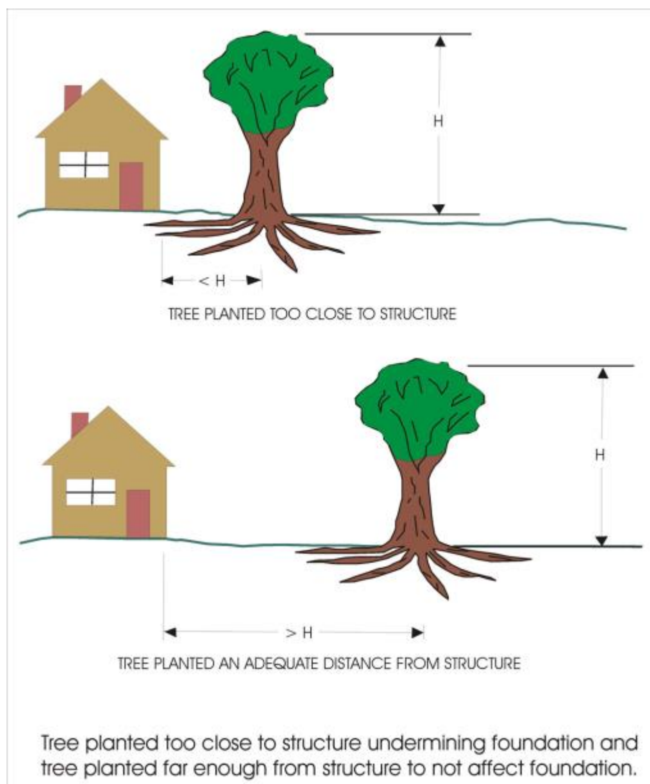


Figure 227. The minimum safe distance for a tree to be from a house on expansive soil is equal to the height of the tree. Image 1948, from Tommy Dunlap's slide presentation.

The standard of at least 7 feet of select foundation fill above the Yazoo Clay is a balance between the likelihood of foundation trouble and the cost of the foundation. The greater the thickness is of the fill cover, the less the chance is of foundation problems, but the greater the cost is of the foundation. For this reason, as a matter of practice, 7 feet of fill are used in home foundations with seven to ten feet of fill being used in the foundations of more expensive commercial buildings.

One example of damage to a commercial building with a slab foundation was a discount store in Clinton, Mississippi, in which the slab heaved some two feet out of level. The store was closed; the building was demolished, and the slab and 8 to 10 feet of the underlying fill and Yazoo Clay were excavated and replaced with an equal thickness of a non-expansive fill buffer. Above this was construction a monolithic beam-on-grade foundation. **Figures 228 and 229** show the form for the beam-on-grade foundation for the interior floor before the concrete was poured.

Figure 228. Form for a monolithic beam-on-grade foundation as viewed from the front of a discount store building in Clinton, Mississippi. The slab of the previous building had buckled some two feet out of level. Picture (digital; Image 1959) was taken on August 8, 2011.

Britt Maxwell of Maxwell Engineering (personal communication) placed the amount of fill buffer needed above the Yazoo Clay at 14 feet rather than seven. This is based on the depth at which the weight of the fill is equal to the swelling pressure of the clay, thus rendering the swell potential to zero. The area above the zero line for potential heave is usually called the active zone (**Figure 230**). In a graph "showing measured heave after 5 years versus depth for two buried expansive clay deposits under a one-story building," Maxwell (2011, p. 21) gave the linear regression lines and formulas for a terrace clay and the Yazoo Clay. In this graph, the linear regression line for the Yazoo Clay intersected the zero heave line at a depth of almost 4 meters or 13 feet.

Figure 229. Form for a monolithic beam-on-grade foundation for a discount sore in Clinton, Mississippi, as viewed from the side. The slab of the previous building had buckled some two feet out of level. Picture (digital; Image 1960) was taken on August 24, 2011.

Commercial buildings with expensive foundations are not immune to damage from expanding (heaving) Yazoo Clay (**figures 231-235**). Maxwell (2011a) discussed the foundation damage done to two commercial buildings about three miles apart in Jackson, Mississippi. The first building was a three-story building built on piers with the first floor on an uneven buffer of fill resting on the natural grade. Below the fill were: (1) a silty clay, (2) a "Terrace clay," and (3) the Yazoo Clay. Concerning this building Maxwell noted that there is typically a perched water table above the Yazoo Clay that is persistent and has a strong influence on heave through a drought. Concerning the second building, a one-story building, Maxwell stated that it was a slab on grade interconnected to a deep drilled pier foundation. As with the first building, this building was built near the highest natural ground on the site with some fill, but with the surface of the expansive soil apparently undisturbed by the construction. It was found in this building that the buried surface of the expansive Yazoo Clay was a hazard because that surface varied under the building. A strong correlation of depth of clay and heave was found in an elevation survey of the shifting slab. The closer the Yazoo Clay was to the slab, the greater the heave.

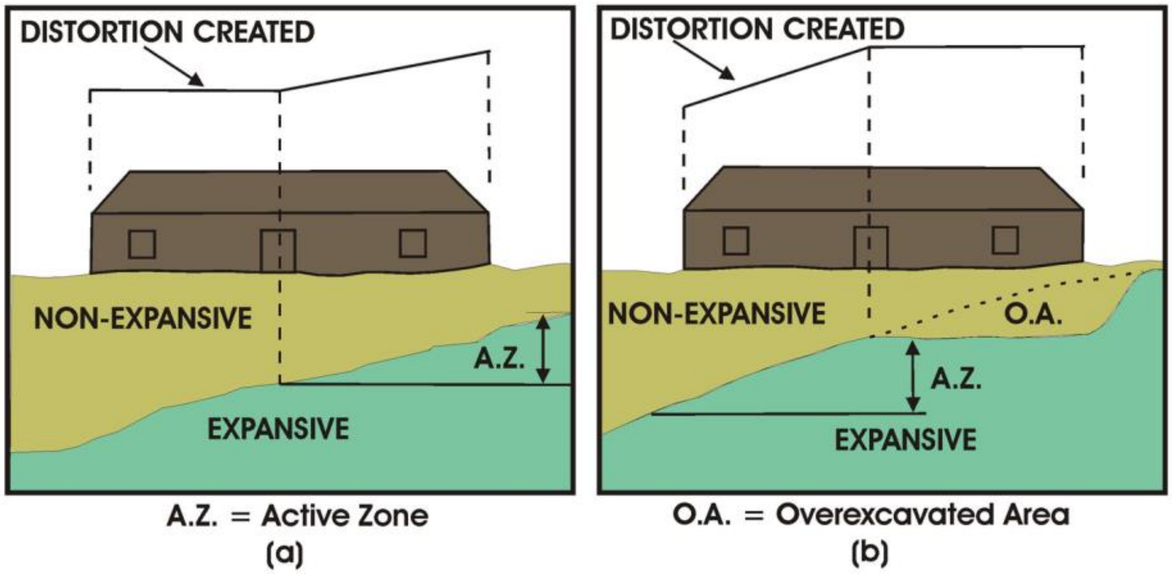


Figure 230. Two cases of damage due to an uneven surface above the active zone (A.Z.) of the Yazoo Clay. At left, the A.Z. slopes under the right side of the foundation, lifting that side up parallel to the underlying slope, while the right side does not move. At right, the entire foundation overlies the A.Z.; the heave causes foundation damage that parallels the underlying A.Z. surface. The right site, where the A.Z. has been over excavated (O.A.) with a flat surface, lifts up horizontally, while the left side is sloped. Image 1976 modified from Maxwell, 2011a.

Figure 231. Damaged due to clay heave at the junction of a drilled pier and beam with a six-inch crawl space on fill overlying the Yazoo Clay in a Jackson apartment building. Picture (digital; Image 1977) was taken by Britt Maxwell in 1981.

Figure 232. Damage inside the apartment building due to clay heave closing up the six-inch crawl space beneath foundation and buckling the floor. The walls are compressed; the sheet rock is torn, and the doorways are warped. Picture (digital; Image 1978) was taken by Britt Maxwell in 1981.

Figure 230 at top illustrates foundation damage due to an uneven surface above the active zone of the Yazoo Clay beneath the structure. At left and above (**figures 231-232**) are pictures of damage to a Jackson apartment building caused by vertical clay heave that closed a six-inch crawl space before lifting the foundation. On the opposite page (**figures 233 -235**) is damage to a three-story nursing home in Jackson caused by lateral heave shearing piers.

Figure 233. A 24-inch concrete pile that was sheared because the Yazoo Clay was removed in a trench from one side to repair a sewer line and not the other side, and because the fill in the trench was not properly compacted. It took just four months for clay to move into the poorly-compacted trench and shear the pile. A total of 32 piers were sheared under the interior cross-beams of a 3-story nursing home in Jackson, Mississippi. Picture (digital: Image 1961) was taken by John Ray.

Figure 234. Replacement pile constructed by Ewing and Ray Foundation Services. A total of 32 piers were sheared by clay movement under the interior cross beams of a 3-story nursing home in Jackson, Mississippi. Picture (digital; Image 1962) was taken by John Ray.

Figure 235. At left, twin piles supporting pike caps with brick pyramids to support the interior beams. These piles were construction by Ewing and Ray Foundation Services to replace piles sheared by clay movement under a 3-story nursing home in Jackson, Mississippi. Picture (digital; Image 1963) was taken by John Ray.

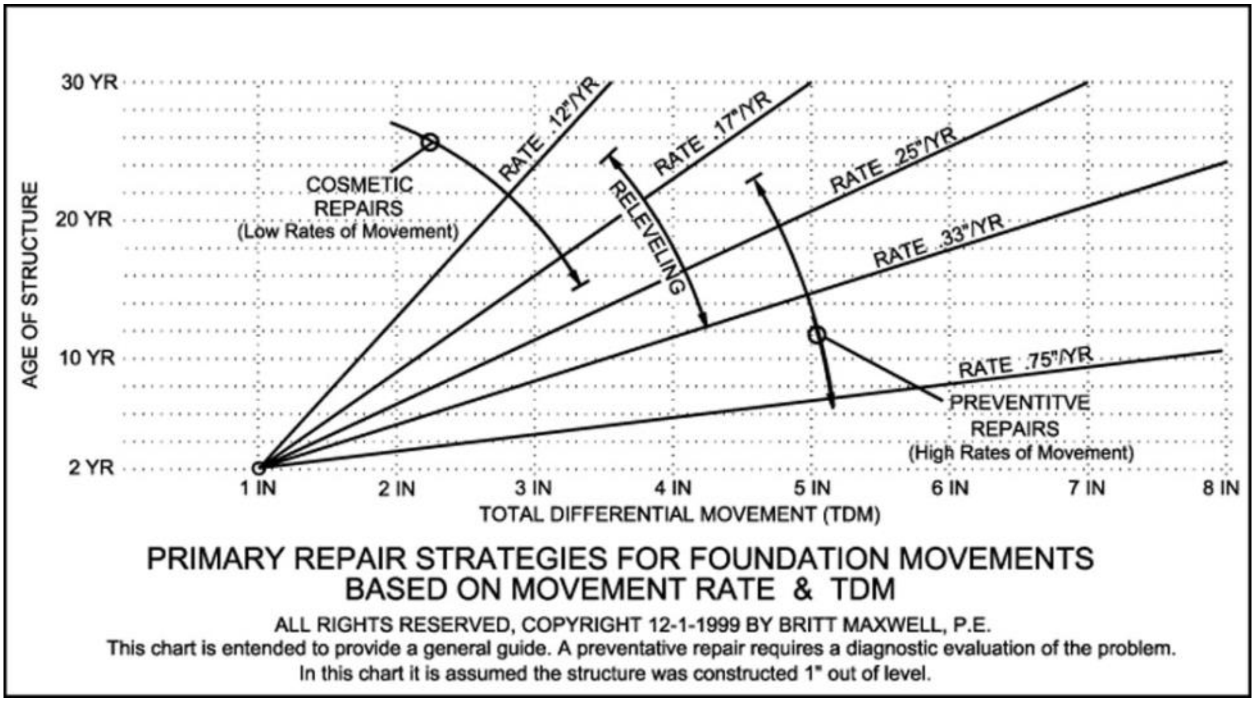


Figure 236. Once heave develops due to Yazoo Clay it continues over the years. This chart by Maxwell matches the rate of heave per year to the level of repairs needed. Image 1964.

Figure 237. Vertical heave of clay around a grade beam, where there was once a 5-foot clearance under the grade beam. Picture (digital; Image 1965) was taken by John Ray.

Figure 238. At right, clay has shrunk under a 20-foot deep pile and left the grade beam resting on adjoining concrete piles. There is a 1.5-inch space between the top of the brick pier that is resting on the top of the concrete pile and the bottom of the grade beam. Picture (digital; Image 1966) was taken by John Ray.

An example of Yazoo Clay causing damage by lateral movement occurred in a 30-year-old, three-story nursing home built on piers in Jackson, Mississippi. A pipe below the building was sheared in the clay and had to be repaired. The pipe was excavated by a trench in the crawl space between two rows of piers and was repaired. The trench was back-filled without sufficient compaction of the fill. Within four months lateral movement of the clay into the poorly-compacted trench sheared the piers on one side of the trench. A total of 32 piers were sheared under the interior cross-beams of the nursing home (**figures 233-235**).

Maxwell (personal communication) found from yearly measurements that the Yazoo Clay tends to heave at a certain rate every year. **Figure 236** shows variable heave rates for the Yazoo Clay and the repair strategies needed for the various rates. **Figure 237** shows clay heave that has closed the space under a grade beam, and **Figure 238** shows where clay shrinkage has left at gap between the grade beam and pier (and all under the same building in Jackson, Mississippi).

Swell Pressure in the Yazoo Clay

According to Eddie Templeton (personal communication), two tests were run on Yazoo Clay samples from the site of the Nissan Plant in Madison County. In the first test, the clay was consolidated under the pressure estimated for the overburden at the plant site, inundated with water, and allowed to swell. Swell pressures in this test ranged from 2.2 to 9.5 tons per square foot (tsf). In the second test, samples were inundated at the beginning, and then loads were increased in an effort to prevent swelling. Swell pressures in this test ranged from 1.0 to 1.8 tsf. If overburden is assumed at 115 pounds per cubic foot, then the overburden would be equal to a swell pressure of 1.0 tsf at a depth of 17 feet and would equal 9.5 tsf at a depth of 165 feet.

Use of Helical Piers in Foundation Repair

Helical piers (**Figure 239**) with grouted columns can carry heavy vertical loads and resist lateral loads. This type of pier was used by Ewing and Ray Foundation Services to lift cell towers, a railroad switch tower, and a pumping station in New Orleans after Hurricane Katrina. **Figure 240** shows the excavated grouted helical pier uncovered to allow another foundation to be set adjoining the existing foundation.

Grouted helical piers were used in making a new foundation for the Grand Opera House in Meridian, Mississippi (**Figure 241**). The Grand Opera House was built by German-Jewish immigrants in the late 1800s at a time that Meridian was a booming timber and commercial center. It was completed in 1890. In 2006, the building underwent a $25 million reconstruction to become the MSU Riley Center for Education and Performing Arts.

Figure 242 shows a specially designed foundation for a house on the Ross Barnett Reservoir. The design includes vertically drilled concrete pilings and helical piers drilled at an angle and grouted for use as soil nails to hold in place the toe of a slope failure associated with the Yazoo Clay.

Figure 239. Installation of a helical pier. Helical piers with a grouted column to carry heavier loads and to resist lateral load. Picture (digital; Image 1000) was taken by John Ray.

Figure 240. A grouted helical pier uncovered to allow another foundation to be set adjoining the existing foundation, where an undercut was required. Picture (digital; Image 1978) was taken by John Ray.

Figure 241. Brick pyramid footings under the Grand Opera House in Meridian, Mississippi, which was built in 1900 and was restored in 2000. Helical piers are in place for a new foundation. Picture (digital; Image 1970) was taken by John Ray.

Figure 242. A special house foundation built on the Ross Barnett Reservoir with concrete piles as part of the foundation and with helical piers used soil nails to hold back the concrete piles and to hold the toe of a slope failure in the Yazoo Clay. Picture (digital; Image 1970) was taken by John Ray.

Figure 243. Excavation and back fill of sand to replace the old concrete drive and parking area of Jackson's downtown Post Office, which buckled with some slab sections higher that others, and replacing it with a new concrete drive. Picture (digital; Image 1967) was taken on August 26, 2011.

Figure 244. Sand back fill and overlying crushed limestone fill (in the distance) for a new concrete drive and parking at Jackson' downtown Post Office. Picture (digital; Image 1968) was taken on August 26, 2011.

Figure 245. The Eudora Welty house in Jackson was re-leveled due to heave damage by the Yazoo Clay. Picture (digital; Image 1969) was taken on August 12, 2011.

Figure 246. Brick damage on the porch of a Jackson home due a shifting foundation. Picture (digital; Image 1970) was taken on August 12, 1011.

Yazoo Clay Damage. Examples of damage in Jackson, Mississippi, caused by the Yazoo Clay, as shown above, include the buckling and replacement of the Downtown Post Office concrete drive and parking area (**Figure 243-244**), the Eudora Welty house in the Belhaven community (**Figure 240**), and an unrepaired brick house on North State Street (**Figure 246**).

The Eudora Welty house in **Figure 245** is shown in its restored condition. The house was built in 1925 and had foundation repairs made in 1979 and 2002. Both repairs were made by Robert Ewing. Soil boring at the four corners of the house showed 5 feet of nonexpansive clay underlain by 22 feet of expansive weathered Yazoo Clay. The unweathered blue Yazoo Clay was encountered at an average depth of 27 feet. In the 2002 repair, the whole house was jacked up and leveled and 50 drilled piers were placed under the foundation, each seated 5 feet into the unweathered Yazoo Clay (Ewing, 2011). In 2005 the Eudora Welty house was placed on the National Register of Historic Places, due to Miss Welty's influence on our national literary heritage and because she did her writing from the her upstairs bedroom.

Repairing the Manship House and Foundation

The first page of *Clarion-Ledger's* January 25, 2013, Metro-State section contained an article by Sherry Lucas entitled "Manship house repairs unearth little treasures." The Manship House Museum, once home to Civil War Jackson Mayor Charles Henry Manship, was closed for repairs in July 2010 after shifting in the Yazoo Clay moved the foundation more than 13.5 inches out of level. This was not the first foundation repair of the structure. In 1980, the foundation was repaired after the building moved 8 inches out of level. The Manship House Museum is part of the museum division of the Mississippi Department of Archives and History. The current foundation repair is Phase One of the building's restoration. Museum division director Lucy Allen described the repair as "major surgery," noting that three chimneys had to be demolished and rebuilt from the bottom up (not to mention lifting the whole house off its foundation on steel I beams). Allen added, "With Phase One, we're on solid footing—no pun intended."

The *Clarion-Ledger* article reported that, in addition to historical artifacts found during the excavation, there were "blue-tinged hunks of fossil-dotted clay" in the "stable layer 40 feet down." In August 2012, I answered a request from Manship House Museum director Marilynn Jones to examine the fossils excavated from the construction of the building's new pilings (**Figure 247**). As it happened, I arrived to examine the excavated spoil when no work-


Figure 247. Left, Manship House with new foundation and reconstructed chimneys. Right, construction of new piling at front of house. Pictures (digital; Image 2317) were taken on January 29, 2013, on left and August 2, 2012, on right.


Figure 248. Left, Yazoo Clay excavated from a hole for a new piling at the Manship House Museum. Left, reverse stratigraphy—weathered brown Yazoo Clay on bottom, unweathered blue-gray clay on top. Right, close up of unweathered Yazoo Clay with chalky fossil seashells. Pictures (digital: Image 2318) were taken on August 2, 2012.

Figure 249. Left, site engineer Britt Maxwell and Manship House Museum director Marilynn Jones. Right, the Manship House rests on steel I beams as a new perimeter skirt foundation is poured by a trailer-mounted boom cement pump. Pictures (digital; Image 2319) were taken on October 5, 2012.

ers were present. The spoil contained cuttings of bedrock strata in reverse order, with the brown weathered Yazoo on the bottom and the unweathered blue-gray clay from the "stable layer" forty feet down on top. The blue-gray Yazoo Clay contained chalky fossil seashells (**Figure 248**).

In October of 2013, work on a new perimeter foundation skirt was underway in spectacular fashion with a trailer-mounted boom concrete pump, pumping concrete over a building to the foundation site (**Figure 249**). Usually when I (Dockery) go with a camera to a construction site, I'm greeted by a big burly foreman who wants an account of what I'm doing—but, not this time. The big burly man was the site engineer, Britt Maxwell, a classmate from MSU (Figure 3). Maxwell has fixed many foundations in the Jackson area and has developed a formula of what to do when a foundation moves on the Yazoo Clay (**Figure 236**). The clay does not move and stop; it keeps shifting over the years.

New Madison County Homes on Slabs. New homes with slab foundations on the Yazoo Clay in a recently-built subdivision in Madison County minimize water saturation around the foundation by sloping the land away from the house in all directions and by the use of downspout diverters to direct rain water away from the slab (**Figure 250**).

Figure 250. Left, a recently-built home in Madison County landscaped with the ground slopping away from the foundation and with downspout diverters that carry rainfall away from the foundation. Right, close-up view of the downspout diverters. Pictures (digital; Image 2320) were taken on February 6, 2013.

Figure 251. Bowed-out walls of Fritzhugh Hall at Belhaven University in Jackson, Mississippi, after a water leak in a 6-inch fire line caused the Yazoo Clay to swell under the foundation, separating the exterior and interior walls. The damaged wing of the building was quickly evacuated of personnel, files, and equipment on December 15, 2011. Picture (digital; Image 2143) was taken on December 16, 2011.

Figure 252. Room 214, Office of the Assistant to the President in the east wing of Fitzhugh Hall at Belhaven University in Jackson, Mississippi, showing cracks at wall joints, the floor, and at windows. Pictures (digital: Image 2144) were taken on December 16, 2011.

Figure 253. Room 213, the Office of Alumni/Annual Giving, in the east wing of Fitzhugh Hall at Belhaven University in Jackson, Mississippi. Picture (digital; Image 2145) was taken on December 16, 2011.

Figure 254. Demolition of the East Wing of Fitzhugh Hall at Belhaven University after the exterior south wall buckled. View of south wall is at left with the original cracks visible in what remains of the first floor; view of north wall is at right. Pictures (digital; Image 2250) were taken on June 30, 2012.

Fitzhugh Hall. The administrative staff who occupied the east wing of Fitshugh Hall at Belhaven University in Jackson had endured cracks in the walls before, but, in December of 2011, a crack between the interior and exterior wall moved as much as six inches within a four week period. The sudden movement in the one-hundred-year-old building came after a leak in a six-inch fire line beside the building. The school hired an engineering firm to check out the building after the water leak. The firm reported to school president Dr. Roger Parrott that something dramatic had happened and that the south wall of Fritzhugh Hall's east wing was in danger of buckling. Parrott reported to WAPT News in Jackson (on December 15, 2011): "You can see that wall is starting to really come out, and the fear, of course, is that it's going to collapse." The structural engineer who examined the building told Dr. Parrott, "You need to move out now." Dr. Parrott asked, "Yeah, what do you mean by now?" The Engineer replied, "Now! No, I mean now. Tomorrow, you've got to be out of the building."

Figure 255. Heaving of the Yazoo Clay beneath a concrete drainage ditch at the intersection of Interstate 20 and Ellis Avenue in Jackson, Mississippi, lifted and shattered the bottom concrete panel of the ditch and lifted the side panels out of place. Picture (digital; Image 2146) was taken on January 7, 2012.

The staff of Fritzhugh Hall's east wing made a hurried exit, moving their files and equipment to other spaces on campus. By the next day, the east wing was abandoned. New locks were placed on entrances to the east wing to keep all the maintenance crews at locked out. **Figures 251-253** show the damaged walls of the east wing on December 16, 2011, a day after the hall was evacuated. On June 29, 2012, with a little help from two trackhoes, the east-wing walls "came tumbing down." **Figure 254** shows the demolished wing the day after, as the trackhoes were loading debris to be hauled to a rubbish landfill.

Figure 255 shows the concrete panels of a drainage ditch on the southeast corner of the intersection of Interstate 20 and Ellis Avenue at Jackson, Mississippi. Heaving in the Yazoo Clay has lifted and cracked the bottom concrete panels of the ditch and has lifted the side panels out of place.

CHAPTER 6. RIVERS AND POLLUTION

River or stream pollution is caused by an excess of any substance that is known to be harmful to desirable living organisms. Pollutants include excess amounts of such substances as heavy metals, certain radioactive isotopes, phosphorus, nitrogen, sodium, pathogenic bacteria and viruses, and even excess amounts of necessary elements and bacteria. Bacteria that feed on decaying organic mater in streams require oxygen. This biochemical oxygen demand (BOD) is measured as milligrams per liter of oxygen consumed over five days at 20° C. The threshold for water pollution is a dissolved oxygen content of less than 5 mg per litter of water. **Figure 256** shows the effect of BOD on dissolved oxygen content in a river when raw sewage is released as a result of an accident or an overflow due to a heavy rain event. Three zones are recognized: (1) the **pollution zone**, where the initial decomposition of sewage produces a high BOD and a reduced dissolved oxygen content, (2) the **active decomposition zone**, where biochemical decomposition drives the dissolved oxygen level to a minimum as the waste is carried down stream, and (3) the **recovery zone**, where BOD is reduced due to depletion of the waste through decay and where the dissolved oxygen level is replenished by stream process (from Keller, 2011).

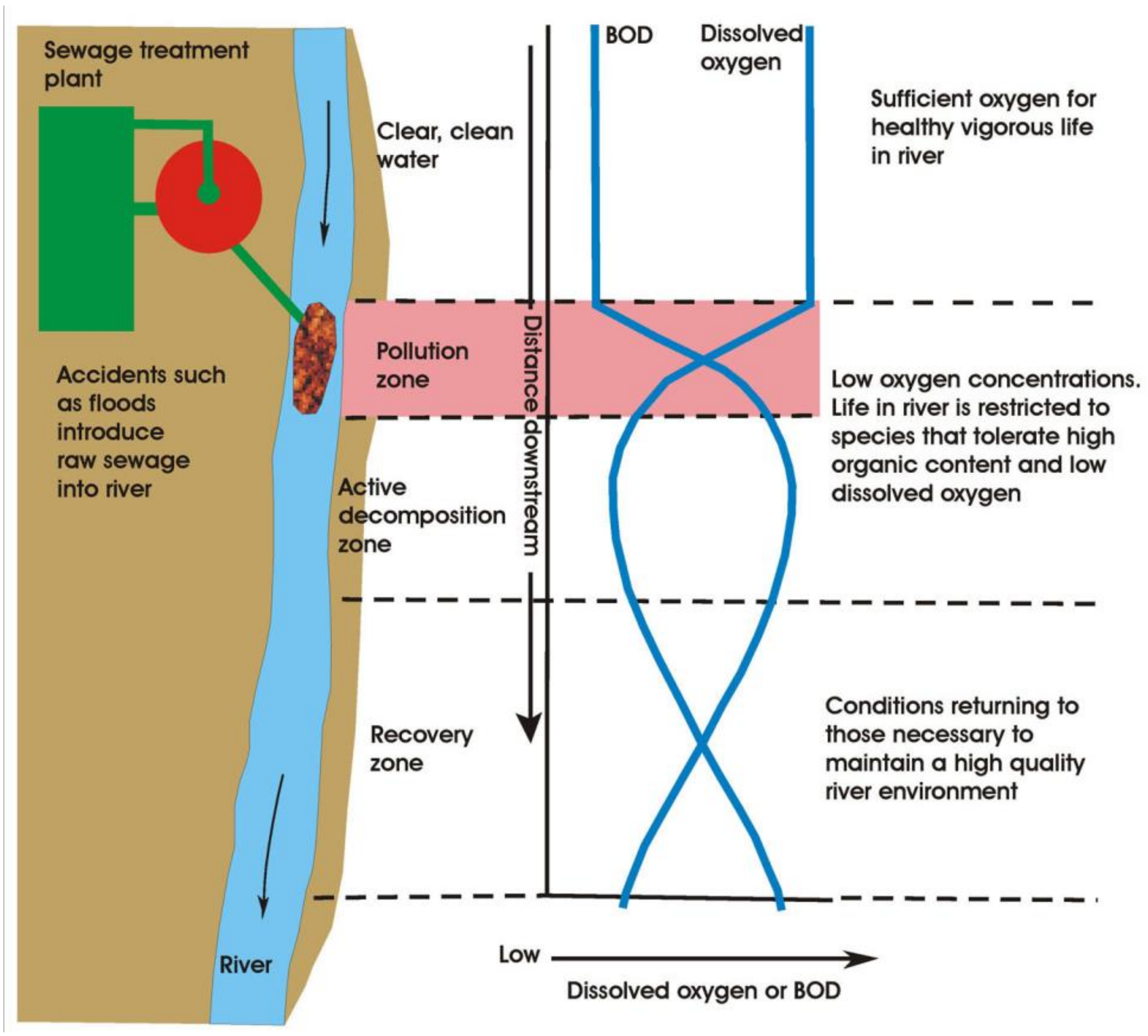


Figure 256. Relationship between dissolved oxygen and biochemical oxygen demand (BOD) from bacteria for a river following the input of untreated sewage. Image 1971 modified from Keller, 2011, p. 375).

POINT-SOURCE POLLUTION

The U.S. Environmental Protection Agency defines point source pollution as "any single identifiable source of pollution from which pollutants are discharged, such as a pipe, ditch, ship or factory smokestack." Factory and sewage treatment facilities are two common types of point sources. Factories with the most frequent point-source pollution issues include oil refineries, pulp and paper mills, and chemical, electronic, and automobile manufacturers.

River systems are especially vulnerable to point source pollution events during summer and fall dry spells at times when the flow is low and the water is warm. Low flow means that the pollution is less diluted with fresh water, and the river water already contains less oxygen when it is warm.

Two fish kills at low flow on the Pearl River in July and August of 2011 illustrate point source pollution events due to heavy rains overflowing sewer lines and holding ponds for industrial waste. On the afternoon of Tuesday, July 12, a strong storm produced heavy rain (1.04 inches of rain at Hawkins Field), lightning, and strong winds that blew down trees in northwestern Hinds County (**Figure 257**). An eyewitness (my wife) stepped outside her front door to see a much-needed rain but was greeted with marble-size hail and swirling winds that picked up flying debris and blew down trees (**Figure 258**).

The following weekend of July 16-17, 2011, it was reported to Michael Bograd, director of the Mississippi Office of Geology, that there were dead fish in the Pearl River near the Lakeland Drive bridge. The director

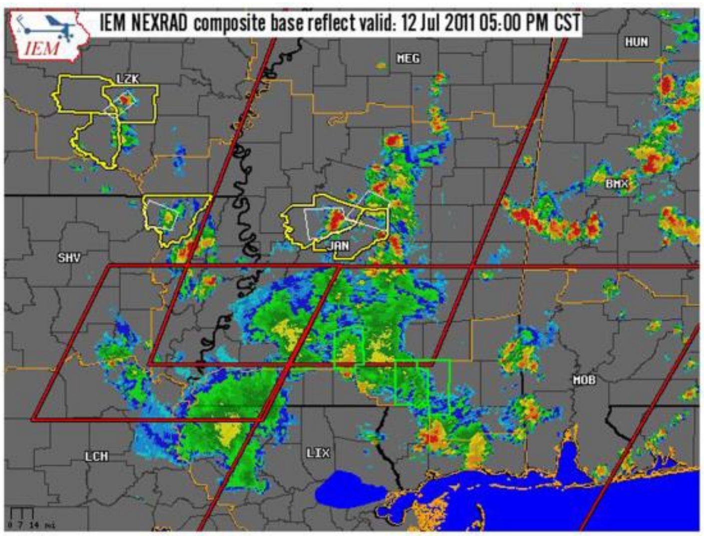


Figure 257. Weather radar show a strong storm in red over eastern Yazoo County about one hour after it passed through western Hinds County with heavy rain, hail, and strong winds on the afternoon of Tuesday, July 12, 2011. Image 1942.

Figure 258. Large tree down across Kickapoo Road after tornado-like hit the area around 4:00 p.m. on Tuesday, July 12, 2011. Picture (digital; Image 1952) was taken on July 12, 2011.

Figure 259. At right, the temporary water contact advisory issued by the Mississippi Department of Environmental Quality on August 18, 2011, for the Pearl River between Highway 25 and Highway 80 in Jackson, Mississippi. Image 1953 from WLBT.com.

Figure 260. Moodys Branch Formation speckled with white fossil shells in the excavation of a sewer tunnel under Jackson, Mississippi. Steel tunnel siding at right and pencil for scale at left. Picture (slide 154-10; Image 173) was taken in September of 1973.

Figure 261. Excavation of the Moodys Branch Formation and Yazoo Clay for the City of Jackson 66-inch sewer line across Town Creek. The excavation material served as a dike to hold back flood waters of the Pearl River from the excavation site. Picture (slide 156-2; Image 525) was taken in May of 1974.

Figure 262. Length-wise view of construction of Jackson's 66-inch sewer mainline in south Jackson just north of Town Creek. The contact between the unweathered (below) and weathered Yazoo Clay can be seen in cut at right. Spoil piles from the cut are at the top right. Picture (slide 156-7; Image 1943) was taken in May of 1974 during flood stage on the Pearl River.

Figure 263. Side view of construction of Jackson's 66-inch sewer mainline in south Jackson just north of Town Creek. Picture (slide 156-8; Image 1944) was taken in May of 1974 during flood state on the Pearl River.

shared this information with the appropriate authorities, and the following Monday on July 18 the Mississippi Department of Environmental Quality issued a temporary water contact advisory for parts of the Pearl River from Eubanks Creek at Lakeland Drive to the Highway 80 bridge (**Figure 259**). Officials said that the advisory was due to the discharge of untreated waste water in the vicinity of Eubanks Creek and Lakeland Drive. In an interview with Marsha Thompson of WLBT News, City of Jackson Spokesman Chris Mims, said that recent heavy rains caused the sewer line to overflow. The spokesman said that this is not the first time this has happened.

During heavy rain and flood events, flood waters can overtop sewer manholes and otherwise backup into sewer lines so that a mixture of flood water and sewage back up in the sewer line until it discharges through other manholes into creeks and rivers. This is especially true for the City of Jackson's 66-inch sewer mainline built in 1975 to carry sewage from north Jackson to the sewage treatment plant in Byram. In the downtown Jackson area, the sewer line was constructed in a tunnel dug under the city (**Figure 260**). This line cut the Jackson levee and was extended in a trench cut across Town Creek in south Jackson (**figures 261-263**).

Figure 264. Box cut in the Jackson 66-inch sewer line near the east end of Rankin Street adjacent to Town Creek. The line was cut at 10 o'clock and 2 o'clock to insert a liner that will protect the concrete pipe from the corrosive effects of sewer gas. The picture (digital; Image 1109) was taken by James Starnes on December 5, 2008, a time of normal sewage flow and of low water on the Pearl River.

Figure 265. Backed up sewage is rising in the box cut, while flood waters of the Pearl River are rising outside the protective levee around the construction site. Between the rising sewage and rising river, James Starnes is collecting fossil seashells excavated from the Moodys Branch Formation. The picture (digital; Image 1110) was taken on December 17, 2008.

Figure 266. Pumps in place to pump sewage from the box cut, around the section of sewer main crossing Town Creek, to another box cut on the other side of the creek. Picture (digital; Image 1947) was taken on December 6, 2008.

Figure 267. Plastic pipes carry sewage around a leaking section of the 66-inch concrete sewer main crossing Town Creek so that repairs can be made and a plastic liner can be inserted. The sewer main can be seen crossing Town Creek in the distance as can the elevated manholes. Picture (digital; Image 1948) was taken on January 27, 2009.

In 2008, sewer gas corroded Jackson's 66-inch sewer main in the vicinity of Town Creek causing a discharge of sewage from the pipe. Sewer gas is formed when sulfate reducing bacteria, which thrive in sewers, reduce sulfur compounds to produce hydrogen sulfide. The hydrogen sulfide escapes as a gas from the wastewater into the air above the flowing liquid, where oxidizing bacteria (in layers of biofilm coating the inside of the sewer pipe) oxidize the sulfur to sulfuric acid. The sulfuric acid then eats away at the concrete or metal sewer pipe. To repair the sewer line, the line had to be excavated and cut for the installation of a plastic interior liner as shown in **figures 264-266**. Sewage had to be pumped from one box cut across Town Creek to another box cut to facilitate work on the damaged section (**Figure 267**).

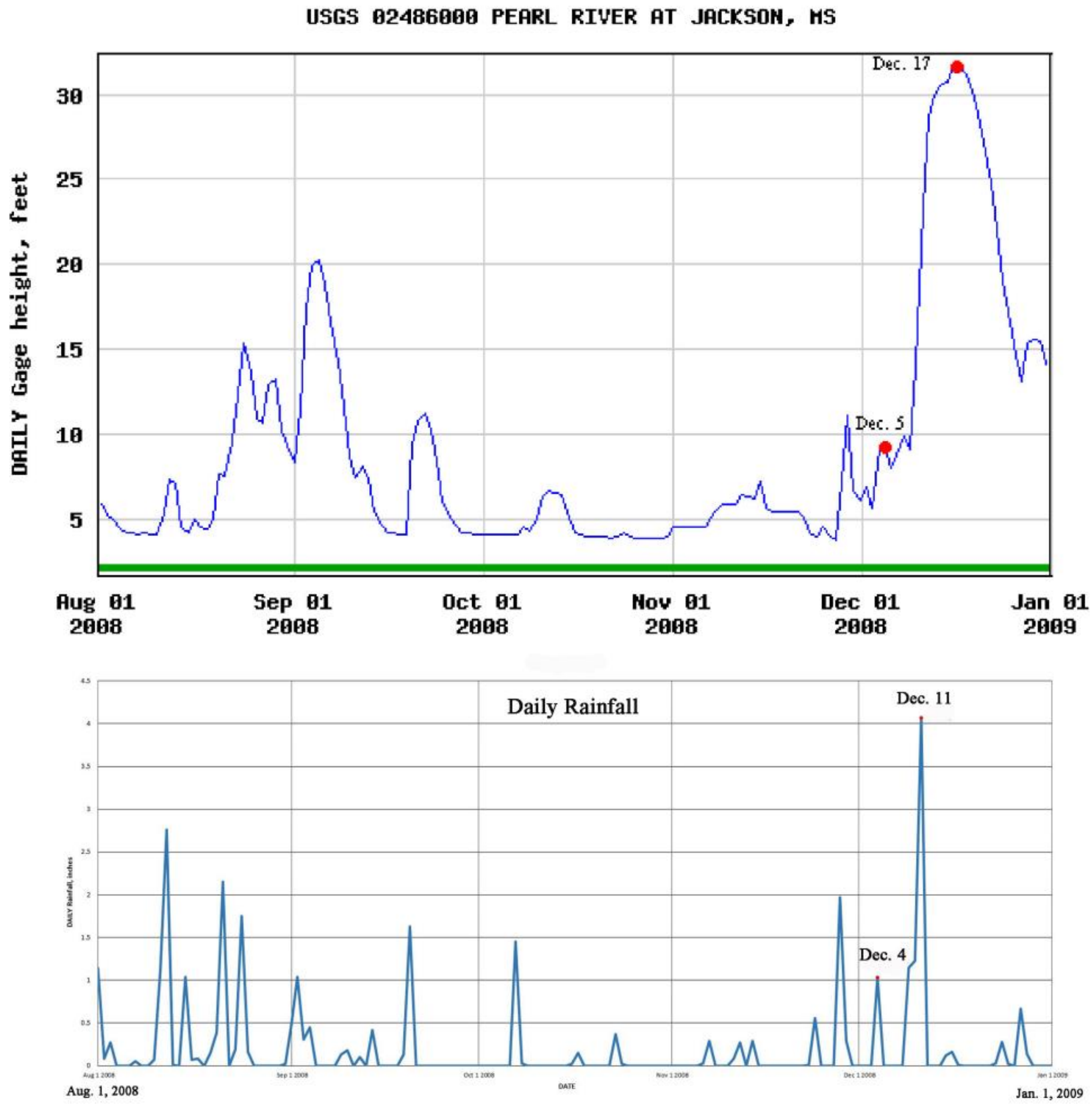


Figure 268, Daily Pearl River gage height in feet at Jackson, Mississippi, from August 1 to December 31, 2008, at top. Daily rainfall for the same period at bottom. Red dots at top mark the low sewage flow seen in Figure 254 on December 5 and the high flow in Figure 255 on Decmeber 17. The flood crest on December 17 follow the heavy rain event on December 11 by six days.

A River Runs Through It: The low and high flows in Jackson's interceptor line as seen in **figures 264** and **265** and in the Pearl River gage height in Figure 258 indicate that the river and interceptor line are hydrologically connected. In Figure 254, the interceptor line is less than half full at a river stage below 10 feet. In Figure 255, the water level in the shaft leading to the line is at the level of the river flood stage above 30 feet. This connection with river water may be due to leakage in the joints of the interceptor line from sewer gas corrosion or from open manholes at low elevations in the Jackson sewer system. Either way the sewage flow to the Savannah Treatment plant is still coupled with the flood stage of the

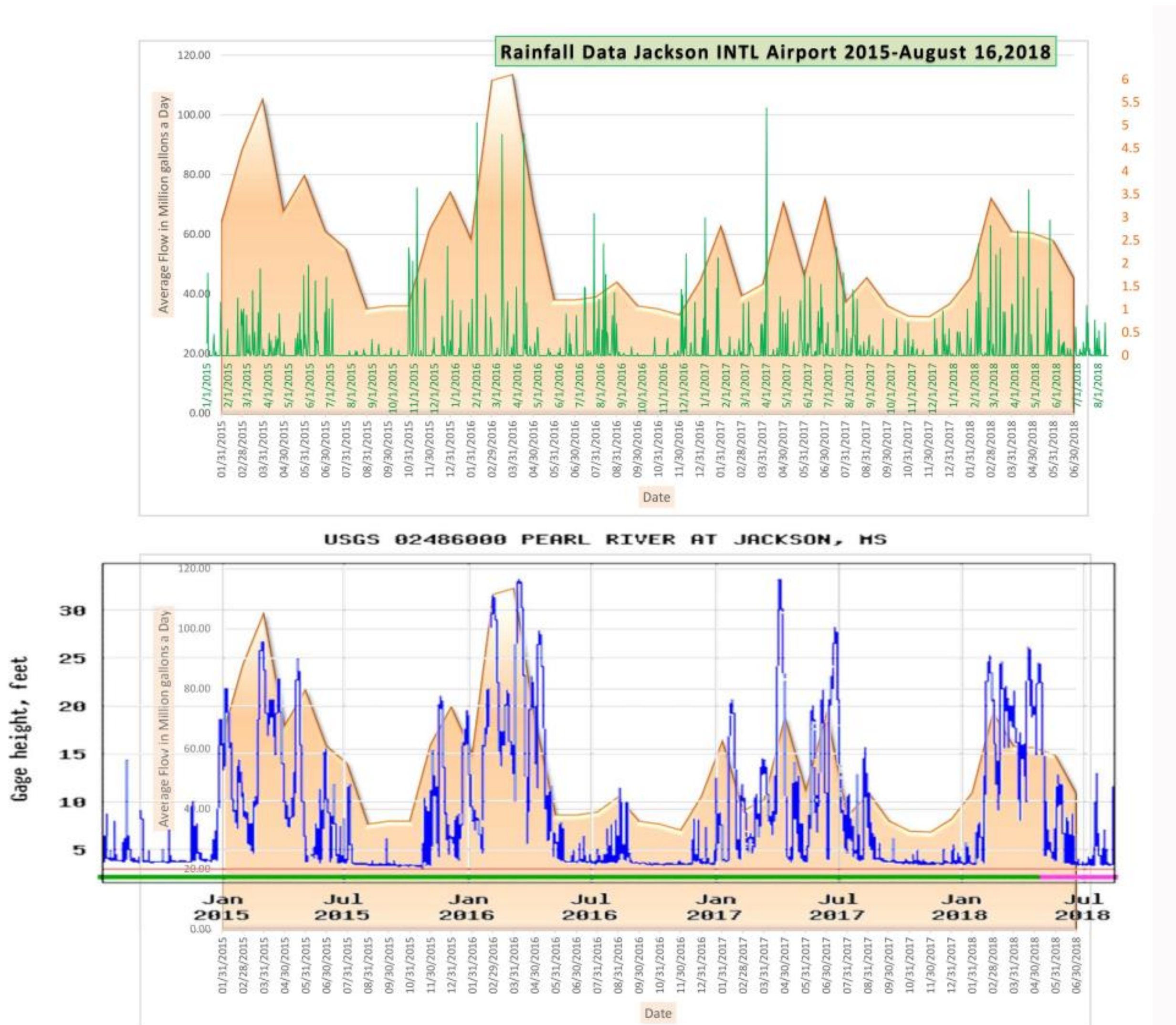


Figure 269. At top, the average inflow per month to the Savannah Treatment Plant shown in brown is overlain by daily rainfall in inches (in green). At bottom, the average inflow per month to the Savannah Treatment Plant is overlain by the daily Pearl River gage height in Jackson (in blue) for a period from January 2015 to June 2018.

river as shown in **Figure 269**. The correlation of rainfall events and river stages to the average monthly inflow into the Savannah Treatment Plant in this figure shows river stages to better correlate with inflow to the plant.

Figures 270 and **271** show the interceptor line exposed where it crosses Eubanks Creek and Town Creek. At the time these satellite images were made, the line was not flooded on Eubanks Creek but was flooded on Town Creek. Manhole covers on the interceptor line are elevated as can be seen in the shadow casted by the one in Figure 261.

Figure 272 at left shows the Jackson sewer system in green, the interceptor line in bold red, and the Jackson and Flowood levees in bold green. At left is a section of the interceptor line in the Jackson Fair Grounds area to be lined, and a section, roughly between High and Pearl streets, that was lined in 2002. Points were the line passes through the Jackson levee and over Town Creek are labeled in bold red.

Figure 270. Jackson sewer interceptor line crossing Eubanks Creek as taken from Google Maps satellite image 2018.

Figure 271. Jackson sewer interceptor line crossing Town Creek in upper right partially obscured by Pearl River flood water. A raised manhole and shadow can be seen at bottom just right of center.

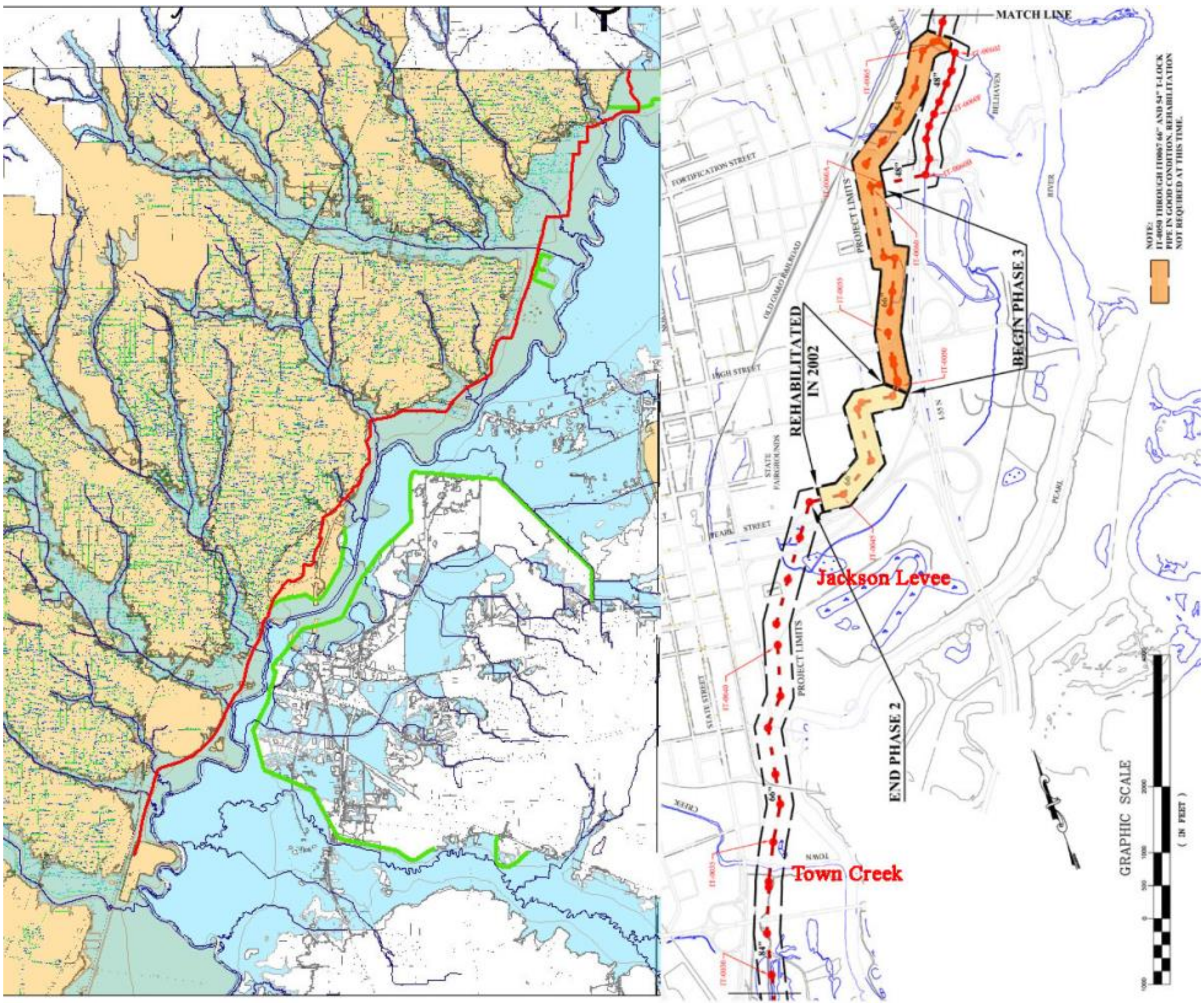


Figure 272. Left, Jackson sewer system in green and interceptor line in bold red. Much of the interceptor line is within the Pearl River floodplain as shown on the flood risk map. Right, section of interceptor line between High and Pearl streets in the Jackson Fairgrounds area lined in 2002 (Phase 2), and section to the north in Phase 3. Map at right by Southern Consultants, Inc.

Pearl River County Fish Kill. On Friday, August 12, 2011, some residents of the Walkaih area northwest of Picayune in Pearl River County noticed that fish were "starving for air." By Saturday, August 13, the river was teeming with dead fish, clams, and even reports of turtles (Picayne Item, August 16, 2011). A fisherman on the river Saturday reported to Jennifer Coulson, President of the Orleans Audobon Society, that the water in the Pearl River "was jet black in color and that a long train of foam was streaming behind the boat engine." He then looked upon thousands of dead and dying fish (Benjamin Alexander-Bloch, The Times-Picayne, August 15, 2011). Frank Lowe, who worked on the Pearl River, gave the following description to Doug Mouton of WWLT Eyewitness News, "The water was black; it was like ink, and you could smell it." Sunday, August 14, the Mississippi Department of Environmental Quality issued a precautionary water contact closure for the Pearl River in Pearl River County in a section

Figure 273. White foam welling up in the Pearl River in Pearl River County, Mississippi, at the point of a "black liquor" release from pipes on the opposite bank next to a Louisiana reporter. The release from a Louisiana paper plant depleted oxygen in the river and killed much of the river's aquatic life. Picture (digital; Image 1955) was taken by Emily Cotton on August 14, 2011.

Figure 274. A dead sturgeon, an endangered fish, floats in the Pearl River in Pearl River County, Mississippi, after a release of "black liquor" from a Louisiana paper plant. Picture (digital; Image 1956) was taken by Charles Thompson on August 14, 2011.

Figure 275. Dead fish on the Pearl River just upstream of Walkiah Bluff Water Park in Pearl River County, Mississippi, killed from a release of "black liquor" from a paper plant in Louisiana. Picture (digital; Image 1949) was taken by Emily Cotton on August 14, 2011.

Figure 276. Bloated dead river mussels found floating in the Pearl River in Pearl River County after a release of "black liquor" from a Louisiana paper plant. Picture (digital; Image 1957) was taken by Emily Cotton on August 14, 2011.

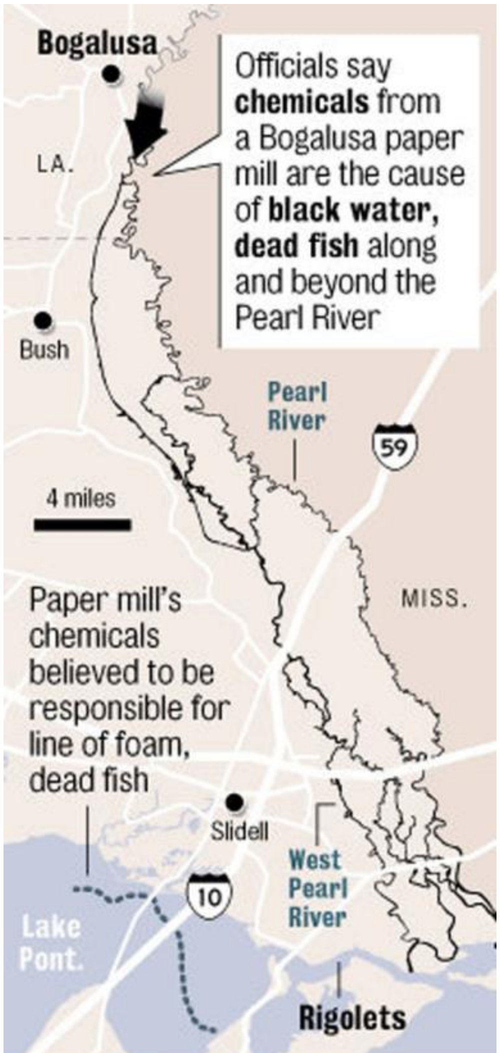


Figure 277. Extent of the fish kill in the lower Pearl River due to a release of "black liquor" by a Louisiana paper plant. Image 1954, from the Times-Picayune.

that extended from Highway 26 near Poplarville south to I-59 near Nicholson (**figures 273 -276**).

In a statement on Monday, August 15, the Louisiana Department of Environmental Quality issued a press release stating that several thousand aquatic animals that live on the top, middle, and bottom of the river were dead or dying, including paddlefish, American eels, catfish, bass, bluegill, and shad. More than 100 boaters and fishermen came to Crawford's Landing in Slidell on Thursday, August 18, to help remove the dead fish from the river before their decay further depleted the river's oxygen level. When interviewed by Steve Phillips of WLOX, Pearl River County Emergency Management Director Danny Manley said, "This was the largest fish kill that anyone I've talked to can ever remember. I've never seen anything like this."

Figure 278. Dead fish still litter the shore of the Pearl River just upstream of Walkiah Bluff Water Park in Pearl River County, Mississippi, days after the initial fish kill cause by a paper plant release of "black liquor." Picture (digital; Image 1950) was taken by Jenny Geraci-Ulmer on August 18, 2011.

Figure 279. Dead river mussels on the banks of the Pearl River just upstream of Walkiah Bluff Water Park in Pearl River County, Mississippi, killed by a release of "black liquor" from a paper plant in Louisiana. Picture (digital; Image 1951) was taken by Jenny Geraci-Ulmer on August 18, 2011.

On Wednesday, August 17, officials from the Temple-Inland plant in Bogalusa acknowledged that a mixture of pulp and chemicals from their paper-manufacturing process exceeded the plant's environmental permits and "might have" depleted oxygen levels in the Pearl River and its tributaries. The pulp mixtures, referred to by plant official as "black liquor," was a byproduct of paper-making with a high pH. This mixture is regularly treated with acid before being released into the river at a pH level allowed by environmental permits. By August 17 the plant's pollution had traveled about 45 miles down the river from its source and had entered Lake Pontchartrain where it formed a line of foam and dead fish. (Katie Urbaszewski, The Times-Picayne, August 17, 2011) (**Figure 277**) . Also on August 17, 2011, the Louisiana Department of Wildlife and Fisheries identified 24 species of fish as part of the fish kill, including 19 endangered Gulf sturgeon (Dustin Barnes, ClarionLedger.com, August 17, 2011) (**figures 278-279**).

The Mississippi Department of Environmental Quality along with officials with Pearl River County asked the Pearl River Water Supply District, which governs the Ross Barnett Reservoir, to increase its daily discharge of water over a two-day period to help dilute the pollution downstream. On August 17, the Pearl River Water Supply District agreed to release an extra 2 billion gallons of water (**Figure 280**) to help purge the river system (an increase in discharge from 255 cubic feet per second [cfs] to 2,145 cfs over a two-day period). That release lowered the reservoir level by three inches (0.25 feet). The travel time for the water to reach the polluted stretch in Pearl River County (and extending to the Gulf of Mexico) took about three days. On August 22 water from the reservoir release increased the river level in Pearl River County by 2.8 feet. Helping the reservoir release was a pulse of freshwater produced by severe thunder storms in central Mississippi on Thursday, August 18. It would be about a month, on September 13, before MDEQ declared the Pearl River between Highway 26 and Interstate 59 to be safe for water contact and fish consumption.

Figure 280. Ross Barnett Reservoir discharge is increased from 255 cubic feet per second (cfs) to 2,145 cfs on August 17, releasing an additional 2 billion gallons of water over a two-day period to flush out pollution downstream. Picture (digital, Image 1979) was taken by Barry McMaster on August 17, 2011.

Jackson, Mississippi's Aging Sewer System. On the front page of the Sunday, October 7, 2012, edition of the *Clarion Ledger*, under the title "H_2Oh, gross," Brian Eason reported that the City of Jackson diverted more than 2.8 billion gallons of mostly untreated sewage into the Pearl River or one of its tributaries in a four-year period from 2009 to 2012. As 19 month's worth of reports on the city's sewage were missing from 2009 and 2010, the problem is even worse.

Based on an analysis of bypass reports filled by the city to the Department of Environmental Quality, Eason noted that there was a risk of city sewage being diverted to local waterway every time it rained—no matter how much. Jackson's Savannah Street Wasterwater Treatment Plant was bypassed at least 50 time over a four-year period. Much of this water was blended with treated water, treated with chlorine, and sent to the Pearl River. There were 700 overflows at broken or clogged sewer lines that diverted sewage to local creeks and ditches, sometimes flooding yards and homes. The city bypassed its treatment plant at least 189 days over the period studied, or about one out of every eight days. Often as little as a half-inch of rain or less was responsible for the bypasses. Most bypasses lasted for days and seven lasted for a week or more.

The city's aging sewer lines are so riddled with holes that storm water seeps in when it rains and river water seeps in when the Pearl River floods. Rainwater carries sediment as it infiltrates sewer pipes clogging pipes and causing roads to collapse (**Figure 281**). The added rainwater pushes the treatment plant beyond the volume it can handle, causing diversions of untreated sewage. These diversions have been noted by the Environmental Protection Agency, which has issued a consent decree in which the city will agree to spend hundreds of millions of dollars to upgrade its sewer system and pay a large fine for violating the Clean

Figure 281. Tammy Estwick and the WAPT News crew at a road collapse above a leaking sewer line under Longino Street between the railroad tracks and West Fortification Street in Jackson, Mississippi. Picture (digital, Image 2264) was taken on July 6, 2012.

Water Act. The city negotiated the decree, the first of its kind in Mississippi, for a period of two years and was waiting for a finalization in October 2012.

Jackson's sewer problem reached a critical mass in the summer of 2009 when bypass treatment became the norm rather than the exception. Just .06 inches of rain on May 25, 2009, and another .44 inches the next day was enough to cause partial bypass for city sewage continuously until July 6, some 42 consecutive days. Millions of gallons of sewage went to temporary holding ponds and then to the Pearl River without treatment. One June 6 report blamed the May 25th half-inch rainfall for a 27 -million gallon discharge. Later in on July 21 and 22, it rained 1.36 inches causing a bypass of 90 million gallons over the next five days. Another 5.23 inches of rain fell from July 26-31, causing a bypass of 160 million gallons that week. Jackson received only 2 inches of rain over a month-period in August and September, resulting of a bypass of 250 million gallons over a 23-day period.

Overflow water at Jackson's sewage treatment plant is held in temporary ponds called storm cells. Over the course of three decades, solids from sewage have completely filled three of these cells. Solids built up in the treatment plant have reduced capacity from an average designed flow of 46 million gallons per day to 35 million gallons. The volume of sludge on the treatment side of the plant equates to 26,000 dump truck loads of solid waste. Compounding the reduced capacity are equipment failures.

Jackson's answer to its sewage bypass problems has been: "dilute, dilute, dilute." The city blends treated water with untreated sewage. The mix is chlorinated to kill bacteria and then dechlorinated to remove chemicals from the water. This method has been effective to some extent in that DEQ had to issue just four water contact advisiories for the Pearl River since 2009. Another nine water advisories were issued for tributaries (creeks) of the Pearl River, eight of which were issued in 2011 and 2012. Easom (2012) compared the blending process to a child urinating in a large swimming pool. "Gross, certainly, but usually unnoticed because there is so much water." The city's sewage-blending process has been a common practice since 1983.

While Jackson awaits the finalization of the EPA consent decree, the bypasses continue. The city bypassed 604 million gallons in March 2011 and another 470 million gallons in September 2011.

Bayou Casotte Closure in Jackson County. MDEQ issued a fishing and water contact closure on August 20, 2013, for Bayou Casotte and adjacent waters of the Mississippi Sound within 1,000 feet of the mouth of the bayou. The closure was due to a fish kill in Bayou Casotte that was linked to the release of low pH waters from the Mississippi Phosphates Corporation. The release came after the company's water storage system was at or near capacity from 62.8 inches of rain from January to August of 2013 (the annual average is 64 inches). An addition 8 inches of rain on the weekend of August 17-18 prompted an emergency discharge that lasted less than 24 hours and ended on 8 a.m. on Monday the 19th. (The Mississippi Press, updated August 20, 2013, 6:30 a.m.). Biloxi Mayor Billy Hewes described a rain event on Sunday, August 18th, which dumped 6.37 inches of rain in about two hours, as a "200-year" rain event (SunHerald.com, published August 19, 2013). The rain made portions of U.S. 90 and 49 look like waterways Sunday until the water subsided. The Biloxi flooding received nation news coverage.

Mississippi Phosphates Corporation is a major U.S. producer of diammonium phosphate, the most widely used phosphate fertilizer for row crops. The production plant is located on a deep-water channel at Pascagoula, Mississippi, with direct access to the Gulf of Mexico and has a maximum annual production capacity of 850,000 tons of granulated diammonium phosphate. Facilities consist of two sulfuric acid plants, a phosphoric acid plant, and a granulation plant.

At the time of the release, Mississippi Phosphate Corporation's Environmental Management System stated that its management was committed to:

1. Minimize pollution in an environmentally and economically sound manner.
2. Minimize releases to the environment.
3. Conserve natural resources through efficient use and careful planning.
4. Recycle materials whenever technically and economically feasible.
5. Disposal of wastes in a manner determined to be environmentally sound.

NONPOINT SOURCE POLLUTION

According to the U.S. Environmental Protection Agency, "Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification. The term "nonpoint source" is defined to mean any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act."

"Unlike pollution from industrial and sewage treatment plants, nonpoint source (NPS) pollution comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them in lakes, rivers, wetlands, coastal waters and ground waters."

One contributor to nonpoint source pollution is the runoff of sediment from improperly managed construction sites, mine operations, crop and forest lands, and eroding stream banks. An example of this is a poorly operated or poorly sited gravel mine (Dockery et al., 2008, p. 18). Mine runoff may produce hydrologic modification, erosion and sedimentation, water quality deterioration, fish and wildlife disturbances, and public nuisances. Hydrologic modifications occur when gravel is mined in the flood plain adjacent to a stream or river or within the stream or river channel. Removal of gravel from a river affects aquatic life and increases erosion upstream and siltation downstream. For these reasons, as of 2002, in-stream gravel mining is no longer allowed a "Notice of Exempt Status" by the Mississippi Department of Environmental Quality (MDEQ). Even in permitted gravel mines not adjacent to streams, topsoil and exposed bedrock are removed as a result of rainfall and erosion (**figures 282-283**). Sediment from mined areas can clog streams unless measures are taken to prevent sediment runoff from the site. Fish and wildlife are adversely affected when runoff from gravel operations disturbs wetlands and streams. Dust, noise, and truck traffic are often cited as public nuisances.

MDEQ is responsible for controlling sand and slit runoff from gravel operations that might potentially leave the mining site and enter the stream, rivers, and other water bodies of the state. This type of pollutions is referred to as both nonpoint source and storm water pollution. There are three aspects concerning mine operation erosion and sediment control: stormwater runoff, gravel wash operations, and water use and the local aquifer.

Storm-Water Runoff. Storm-water runoff consists of rainfall that hits the disturbed ground of the gravel mine. This disturbed ground, as well as associated stockpile areas of sand and gravel, are highly susceptible to erosion. To prevent erosion, mines must have a Stormwater Pollution Prevention Plan required by MDEQ for a general Stormwater permit. Water flowing from the mine site must be slowed down by the use of check dams (dirt berms), gentle slopes, silt fences, hay bales, rock culverts, and other methods. The water should eventually flow into sediment ponds where the sand, silt, and clay can settle out. Clean water from these ponds can be pumped into streams or rivers.

Figure 282. Highwall at the Hammett Gravel Company Zeiglerville pit in Yazoo county, where 25 feet of loess overlies 25 feet of gravel. Picture (digital; Image 950) was taken on November 9, 2007.

Figure 283. Active gravel mining operations at the Hammett Gravel Company Zieglerville pit in Yazoo County. Picture (digital; Image 1975) was taken on November 9, 2007.

Gravel-Wash Operations. Gravel-wash operations separate gravel from finer sediments and sort the gravel by size in shakers containing sieves of different sizes (**Figure 284**). Gravel is sorted into pea-size, pebble-size, and over-sized. The pea-sized and pebble -sized gravel is used in concrete and for gravel driveways. The over-sized gravel is used in drainage systems for landfills or is crushed into angular fragments which are used as aggregate in asphalt for road surfaces. Fine sediments, consisting largely of sand, from the washing operation are drained into a pond or lake dredged for that purpose and do not leave the site. When the pond is full, the sand is dredged out and stockpiled for future use. Sand that is not sold can be used as fill material when the gravel pit is reclaimed (**figures 285-286**).

Mine Dewatering. There are two methods for mining gravel layers that lie beneath the water table. One method is to dredge the gravel from the flooded pit floor using a pump and a suction pipe that delivers a slurry of gravel, sand, and water to the mine operation (**Figure 287**). The second method involves dewatering the mine site. This is accomplished by drilling water wells and pumping down the ground-water table until it is below the gravel deposit.

Figure 284. Gravel washing operation located at the Hammett Gravel Company Zieglerville pit in Yazoo County. Gravel is transported to this site by a conveyor belt from the active mine, which is more than a mile away. Picture (digital; Image 1973) was taken on November 9, 2007.

Figure 285. Sand draining from gravel wash operation forms a delta at the head of a containment lake. The conveyor belt that transports the gravel to the gravel wash is at the lower right. Picture (digital; Image 1972) was taken on November 9, 2007.

Figure 286. Stockpiles of sand dredged from the containment lake at the Hammond Gravel Company Zieglerville pit in Yazoo County. Picture (digital; Image 1974) was taken on November 9, 2077.

Figure 287. Gravel dredge at Hammett Gravel Company pit in Yazoo County. Picture (slide 375-28; Image 33) was taken on May 5, 2004.

Forensic Geology and Nonpoint Source Pollution

The following account and figures are from Oivanki (1996) and concern a Mississippi Office of Geology study made at the request of the Storm Water Section of the Office of Pollution Control in 1993 to identify the source of nonpoint source pollution from sediment runoff in Woodland Lake, a 14.6-acre lake in Olive Branch, Mississippi. The lake was built in the 1950s and was fed by a small stream with a limited watershed of about 450 acres. The stream historically drained an agricultural area with row crops. The lake supported a prolific and varied aquatic fauna and had no reported problems since its construction.

In 1991, construction began on a subdivision within the drainage basin upstream from the lake. After construction began, residents around the lake noticed an increase in the sediment content of the lake water. A sediment delta was rapidly forming at the head of the lake where the stream entered (**Figure 288**).

Figure 288. Stream delta formed at the head of the subdivision lake. Picture (scanned negative; Image 1980) from Ovanki, 1996, p. 46.

Figure 289. Construction site showing extensive soil erosion due to rain runoff. Picture (scanned negative; Image 1981) from Ovanki, 1966, p. 47.

The Office of Geology was asked to identify the source or sources of the sediment pollution as well as the amount of sediment from each source. This required sampling the sediment column in the lake bed and strata from specific localities within the drainage basin (**Figure 289**). Lake bed sediment would then need to be correlated with probable sources and with known historical events since the lake was constructed. As there were no mineralogical differences within the drainage basin, sediment sources were correlated with those of the lake bed by grain size differences.

Four vibracores were collected using the Office of Geology vibracore rig. This rig consisted of a portable gasoline-powered concrete vibrator with the vibrating head clamped to a 3-inch diameter aluminum pipe. With the tubing upright on the lake bottom, the action of the vibrator liquefies wet sediment in and around the pipe, allowing the pipe to descend through the sediment and collect an undisturbed sediment core. The open top end of the pipe is plugged to retain sediment column by suction, and the pipe is pulled from the bottom with a winch cable. The sediment-filled pipe is later cut lengthwise and laid open for examination and analysis of the enclosed core. Later another ten vibracores were taken to effectively sample the entire lake bottom. Lake depths were surveyed from the top of the dam using a prism rod placed on the lake bottom, and the survey was tied to the elevation of the dam spillway.

Most vibracores contained at least two distinct layers of concentrated organic material located near the top of the sediment column. As the lake's bottom fauna, such as mussels, would routinely rework and disseminate organic material, the presence of two distinct organic accumulations in the top half of the sediment column was unusual. Their presence could only be explained by rapid deposition and the preservation of seasonal fall/winter leaf litter. Construction of the development upstream began in 1991, so there would have been at least two and possibly three annual defoliation events prior to collection of the cores in 1993 and 1994. Thus the two organic layers corresponded to the fall defoliation events of 1992 and 1993, which were buried by sediment runoff and accumulation from the new subdivision.

Figure 290 is a grain size analysis of samples from the construction site, the stream bed, the lake bed, and a stream tributary in an agricultural area within the basin. The difference in sediment size shown on the graph indicates the agricultural source to be much finer grained than the other sources, thus eliminating it as the source of sediment contamination for the lake. **Figures 291-293** show oblique depictions of the lake bathymetry when sampled in the spring of 1994, the reconstructed bathymetry by subtraction of annual sediment layers for the year 1992, and the original lake bottom prior to any sediment fill since construction in the 1950s.

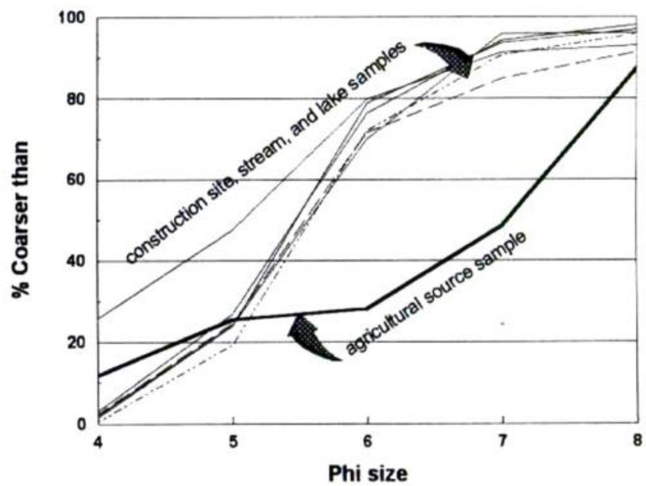


Figure 290. Grain size analysis data for samples from the construction site, the stream bed, the lake bed, and a stream tributary sourced from agricultural areas. Image 1982 from Oivanki, 1996, p. 49.

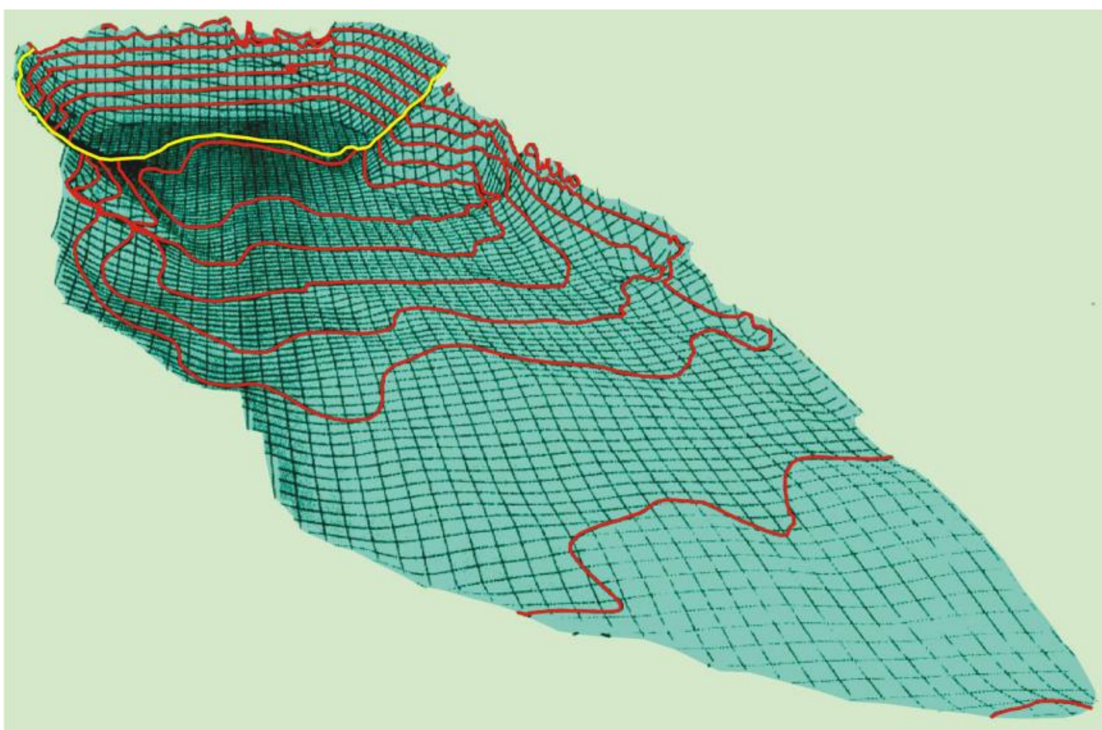


Figure 291. Perspective of the present (1994) lake bathymetry. View is looking toward the dam (Dam perimeter is in yellow) from the head of the lake. Shaded (grid) area is below the water surface. The contour interval (in red) is one foot. Image 1983 from Oivanki, 1996, p. 48. Figure modified from the original by Barbara Yassin, 1994.

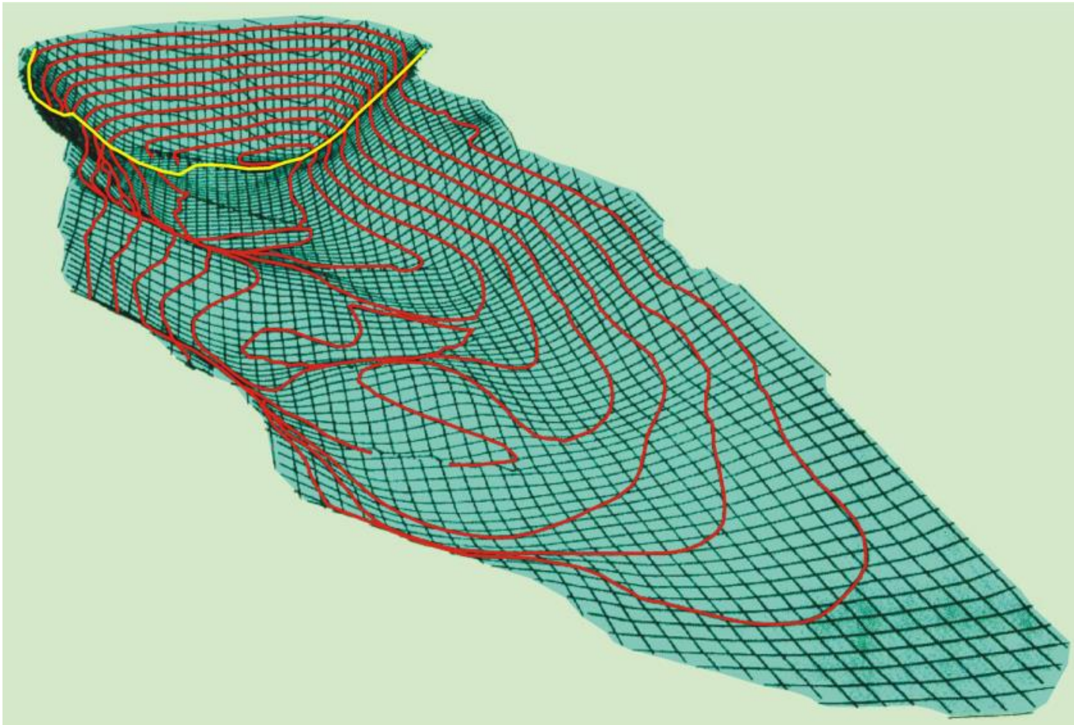


Figure 292. Perspective view of the lake bathymetry prior to the 1992 annual leaf fall event (calculated form core data). Shaded (grid) area is below the water surface. The contour interval (in red) is one foot, and the dam perimeter is shown in yellow. Image 1984 from Oivanki, 1996, p. 49. Figure modified from the original by Barbara Yassin, 1994.

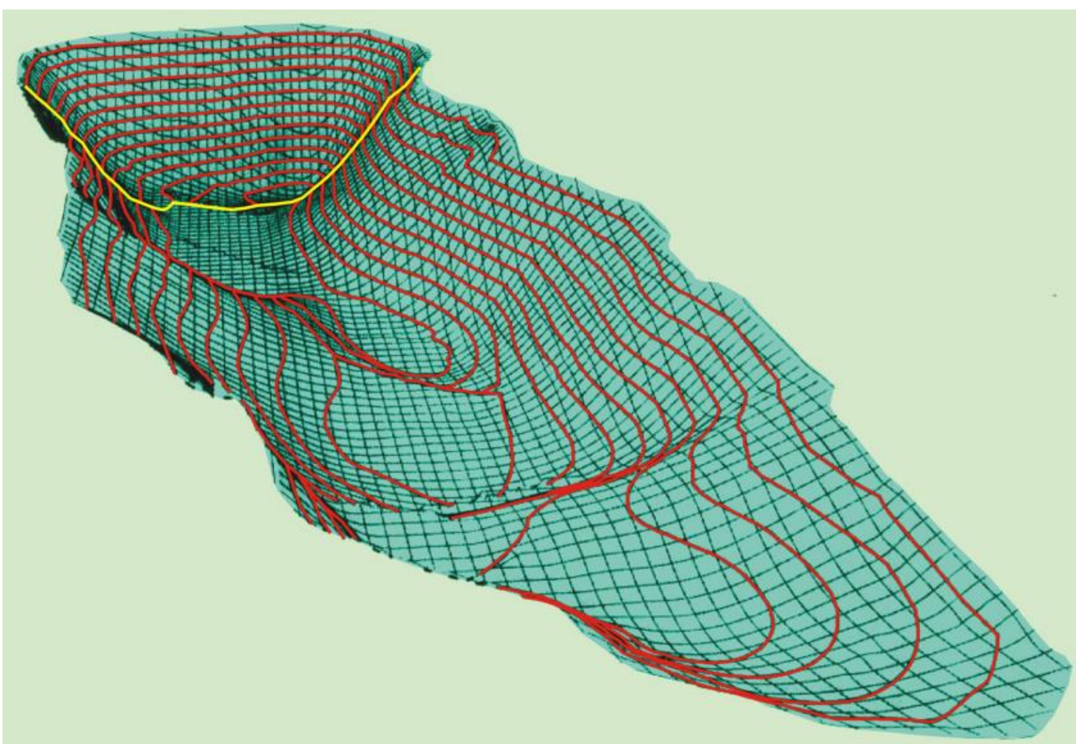


Figure 293. Perspective view of the original lake bathymetry in the 1950s prior to any sediment fill (calculated from core data). Shaded (grid) area is below the water surface. The contour interval (in red) is one foot, and the dam perimeter is shown in yellow. Image 1985 from Oivanki, 1996, p. 50. Figure modified from the original by Barbara Yassin, 1994.

In-Stream Gravel Mining

In-stream gravel mining is detrimental to steam habitat and accelerates erosion upstream and siltation downstream (**Figure 294**). Much of this gravel is used as road metal on gravel roads, the gravel being the agent that prevents the road from washing away in rainstorms. Gravel works the same way in the bed of a stream in preventing erosion of the steam bottom. In a U.S. Geological Survey report entitled "Instream gravel mining and related issues in southern Missouri" (USGS Fact Sheet 012-02, February 2002) Suzanne Femmer gave

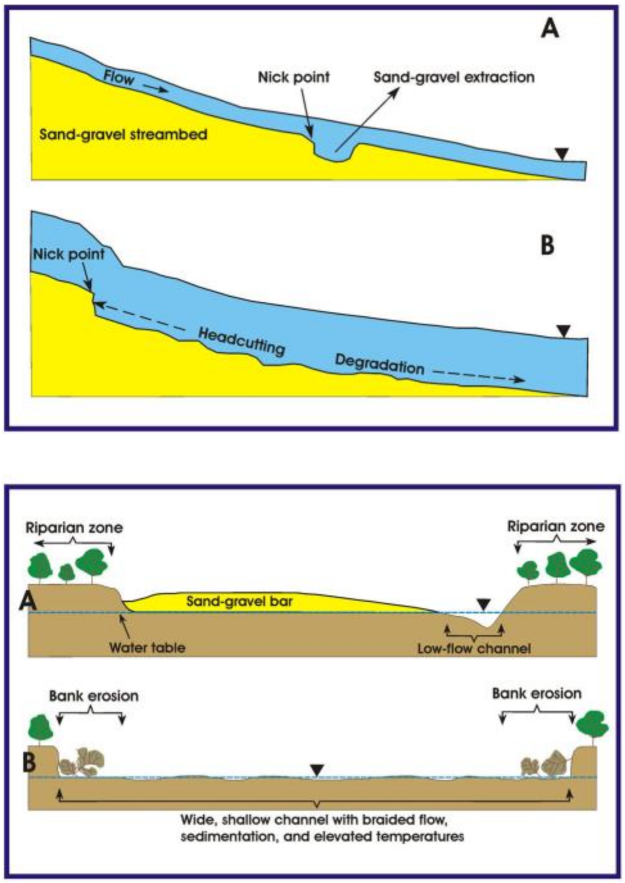


Figure 294. At top, Nick point migration , headcutting, and stream degradation due to sand and gravel extraction from a stream/river. At bottom, bank erosion due to sand/gravel bar mining, from figures 1 and 2 of Sand Mining Facts, Ojos Negros Re-

the known effects on in-stream mining as follows: "Extraction of gravel from a stream alters the sediment budget creating the potential for channel instability, increased turbidity, and degradation of habitats …. Instream gravel mining may be linked to loss of fishery resources and wetlands, increased bank erosion, and damage to infrastructure caused by channel degradation."

Due to problems caused by instream gravel mining, the Mississippi Surface Mining and Reclamation Rules and Regulation (Mississippi Code Annotated § 53-7-11) in Chapter 4, page 29, #7, states that "...it is unlawful to conduct surface mining operations within an area designated as unsuitable for surface mining, or to conduct surface mining operations in rivers, lakes, bayous, intermittent or perennial streams or navigable waterways, natural or manmade, without a permit or coverage under a general permit issued or reissued consistent with these Regulations." While technically such a permit is possible, one would be very difficult to get.

Figure 295 is a poster by the Mississippi Department of Wildlife Fisheries and Parks concerning the use of all-terrain-vehicles in stream beds. It cites Mississippi Code 51-1-4, stating "...Nothing shall authorize any person to disturb the banks or beds of public waters." In explanation the poster notes that: "The improper use of ATVs disturbs streambeds, stirs up sediment, and degrades water quality, especially during spring and summer low flows. This destroys spawning beds, newly hatched fish and their food source." If ATV tires are hazardous to fish and their habitat, how much more so are the tires of a frontend loader mining gravel from stream bottoms?

In-stream Mining is a Global Problem

Countries that prohibit in-stream mining include the United Kingdom, Germany, France, the Netherlands, and Switzerland, and this activity is restricted in select rivers in Italy, Portugal, and New Zealand (Kondolf, 1997) and is not allowed in Saskatchewan or most of Canada (Starnes and Gasper, 1996). The *River Sand Mining Management Guidline* (September 2009) published by the Ministry of Natural Resources and Environment of the Department of Irrigation and Drainage of Malaysia noted that the "mushrooming of river sand mining activities" had given rise to various problems that required urgent action. These problems included "river bank erosion, river bed degradation, river buffer zone encroachment and deterioration of river water quality." Figure 2.9 of the Malaysian report, gave an example of the damage caused by in-stream mining and headcutting over a five-year period at an unspecified site. The two pictures in the figure were taken from Langer (2003) and were of the Amite River in Mississippi. (see **figures 305-310**). **Figure 294** is modified from figures 1 and 2 of Sand Mining Facts, a web publication of The Ojos Negros Research Group. The Ojos Negros Valley is located in Baja California about 80 kilometers south of

Figure 295. Poster against the use of all terrain vehicles (ATVs) in stream banks or beds of public waterways. The poster is sponsored by: (1) Mississippi Department of Wildlife, Fisheries and Parks, (2) Mississippi's Sheriff's Association, (3) Mississippi Museum of Natural Science, (4) Mississippi Wildlife Federation, (5) Mississippi Farm Bureau Federation, Mississippi Forestry Association, Mississippi Department of Environmental Quality, Mississippi Forestry Commission, Pearl River Basin Development District, and Mississippi Department of Marine Resources. Image 2006.

the U.S.-Mexico border.

Migrating Knickpoints and Headcutting Erosion Due to Channelization and Gravel Mining

Gravel mining operations can cause streambed erosion that works its way upstream as a knickpoint, causing headward erosion. A knickpoint is defined as "Any interruption or break of slope; especially a point of abrupt change of inflection in the longitudinal profile of a stream or of its valley" (Bates and Jackson, 1984). **Figure 294** shows the formation of a knickpoint caused by the in-stream mining of gravel. This knickpoint then moves upstream over time. Such headward erosion can damage bridges and cause erosion along the banks of valuable farmland and tracks of timber as well as destroy fish and other aquatic habitat. Solutions to stop headward erosion include low-price fixes such as rip-rap barriers (**Figure 297**) and high-price fixes such as reinforced concrete weirs (**Figure 298**). The following discussion of the Bayou Pierre, Homochitto, Amite, and Buttahatchee rivers is taken from Carol Hardy's PowerPoint thesis defense.

The physical effects of removing the gravel armor from the river bed by mining can be characterized by headcutting as follows (Patrick et al., 1993):

1. Creation of a knickpoint at the upstream end of mined reach.
2. An increase in water velocity that scours the channel and concentrates on the knickpoint.
3. Knickpoint is eroded away, causing erosion activities to travel upstream until more erosion-resistant channel material creates a

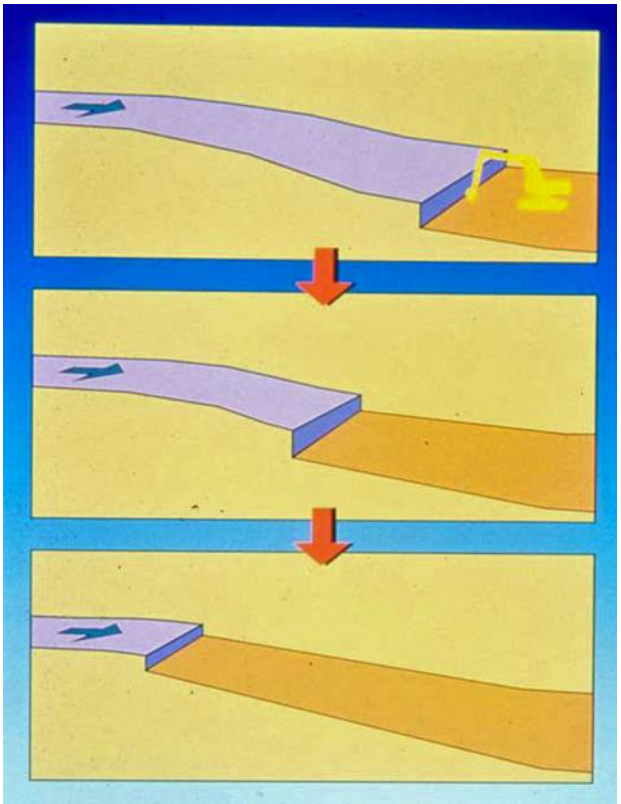


Figure 296. The formation of a knickpoint in stream gradient due to in-stream mining of gravel. Overtime the knickpoint moves upstream. Image 2026 from Carol Hardy's master thesis presentation.

new knickpoint.

4. Erosion of channel bed and banks.
5. Deepening of channel.
6. Decrease in sinuosity of stream channel.
7. Oversteeping of channel banks.
8. Collapse of channel banks.
9. Increased sinuosity of stream channel as stream begins to meander through accumulated sediment lying on the lower channel floor.
10. Loss of thousands of acres of land and millions of board feet of timber to landowners in Mississippi and Louisiana.

Paul Hartfield (1994) recognized the following physical effects of headcutting on Mississippi streams.

1. Extensive bank erosion.
2. Numerous whole trees within the channel.

Figure 297. Rip-rap barrier placed across a tributary of the Homochitto River in the Homochitto National Forest to prevent headcutting erosion. Picture (digital; Image 2019) was taken by Carol Hardy.

Figure 298. Construction of a reinforced concrete weir across Little Tallahatchie River southwest of Dumas in Tippah County, Mississippi. Picture (color negative 617-3, DVD 57; Image 2030) was taken on August 9, 2007.

3. Wide degraded channels.
4. Meander cutoffs.
5. Quicksand or loose unstable sediments.
6. Perched tributaries at low water.
7. Absence of tree species characteristic of stable riparian ecosystems.
8. Channel stabilization efforts around bridges.
9. Bridge replacement due to erosion activities.
10. Channel stabilization efforts around other

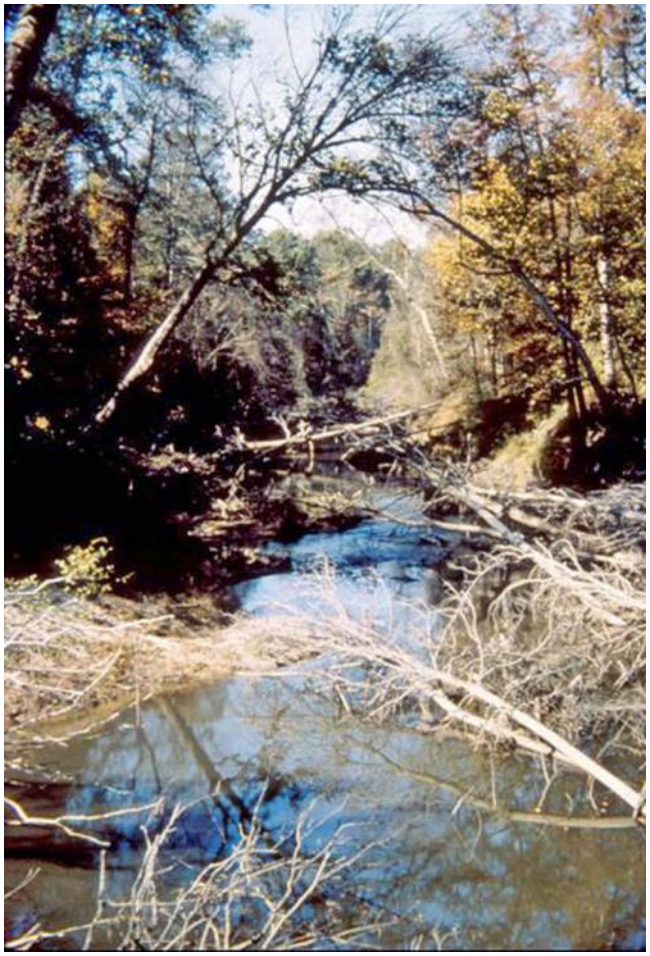


Figure 299. Bayou Pierre at Smyrna in Copiah County in 1983 before headcutting. Picture (slide; Image 2022) was taken by Paul Hartfield in 1983.

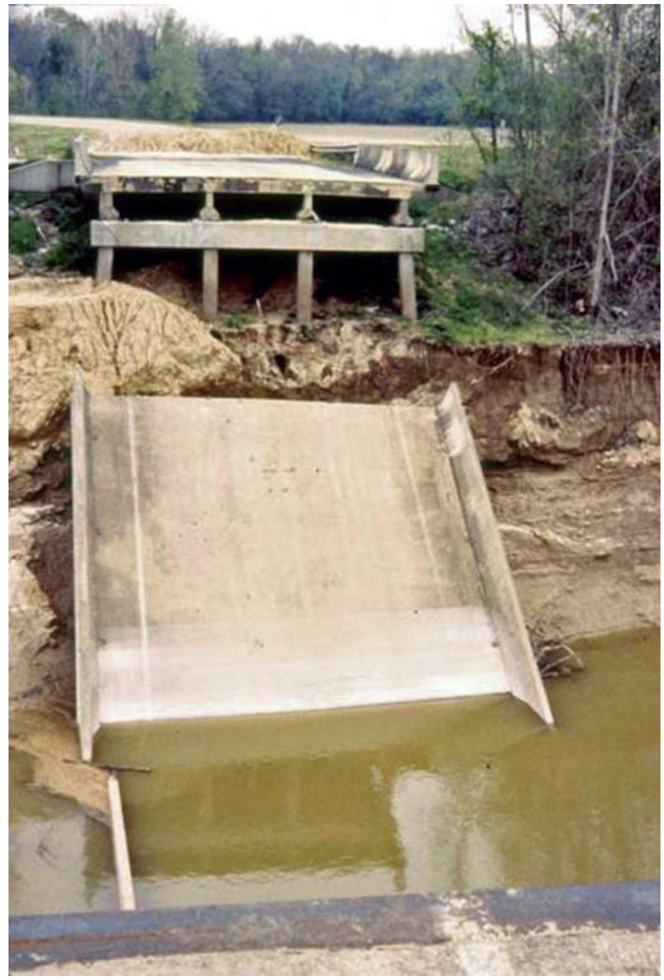


Figure 300. Bayou Pierre bridge failure in Claiborne County due to headcutting in 1999. Picture (slide; Image 2025) was taken by Paul Hartfield in 1999.

Figure 301. Bayou Pierre at Smyrna in Copiah County in 1985 after headcutting (same location as in Figure 260). Picture (slide; Image 2023) was taken by Paul Hartfield in 1985.

Figure 302. Bayou Pierre at Smyrna in Copiah County in 1995 beginning to stabilize after headcutting (same location as figures 260 and 262). Picture (slide; Image 2024) was taken by Paul Hartfield in 1995.

Figure 303. Aerial image (2017) of knickpoints heading upstream on Bayou Pierre (center) and a tributary (upper right) toward Highway 28 in Copiah Couonty west of Hazlehurst, Mississippi. The channel is wide and sandy downstream from the knickpoints (at top of image) and narrow with tree-covered banks upstream of the knickpoint. Image 2525.

Figure 304. After headcutting dropped the channel 5.4 meters, the Homochitto River channel at low water is now filled with sand and is 0.4 to 0.8 kilometers wide. Picture (slide; Image 2032) was taken by Paul Hartfield.

Figure 305. Gravel mining on Amite River point bars in Louisiana. Picture (slide; Image 2033) was taken by Paul Hartfield.

Examples of migrating knickpoints and headcutting in Mississippi include the Bayou Pierre, Homochitto, Amite, and Buttahatchee rivers.

Bayou Pierre. The Bayou Pierre River has experience active headcutting due to channelization work on the Mississippi River following the 1937 flood. Freshwater mussel collection trips from 1980 to 1983 found 12 species near Smyrna in Copiah County (**Figure 299**). By 1985, a knickpoint had reached the area (**Figure 301**), migrating upstream at a rate of 560 feet per year (Patrick et al., 1991). Repeated trips since 1985 have found no living mussel in the area (**Figure 302**). **Figure 300** shows a bridge collapse over the Bayou Pierre River in Claiborne County due to headcutting erosion. Heitmuller et al., 2017,estimated that the Bayou Pierre knickpoint could compromise the Highway 28 bridge by the year 2028 (**Figure 303**).

Homochitto River. The lower portion of the Homochitto River was channelized between 1938 and 1940. Active headcutting has progressed steadily up the river and is currently affecting the headwater reaches (Patrick et al., 1993). In 1940, a stretch of the Homochitto some 40 miles from the river's mouth had a low channel width of 29 meters and average depth of 1.2 meters. In 1978, that same stretch has a low water channel width of 100 meters and an average depth of 3.0 meters (**Figure 304**). The river channel has dropped an estimated 5.4 meters since the time of its channelization. The channel is now sand-filled and is 0.4 to 0.8 kilometers wide. Between 1945 and 1974 at least 8 bridges have been lost due to river channel instability, costing some $10 million. Freshwater mussel surveys in the 1980s found only 8 living species. Those in the 1990s found only 4 living species.

Amite River. The Amite River drains portions of southwestern Mississippi and southeastern Louisiana before ending in Lake Maurepas (**figures 305-310**). Active and abandoned gravel mines occur along a 48 kilometer reach of the river in Louisiana. This reach is mined at estimated rate of 140 acres per year. In the 1980s, 32 mussel species were found in surveys of the river (Vidrina, 1985). In the 1990s, headcutting activities had traveled into the headwater region and only 12 mussel species were found in reaches above the mines (Hartfield, 1992).

Figure 306. Paul Hartfield at a point-bar gravel mine on the Amite River in Louisiana. Picture (slide; Image 2034) from Paul Hartfield.

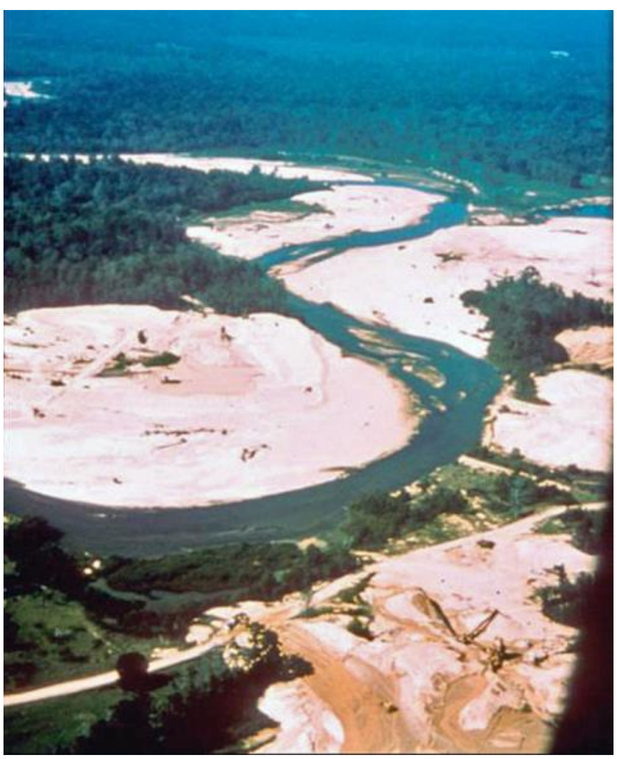


Figure 307. Areal view of gravel mines on Amite River point bars in Louisiana. Picture (slide; Image 2035) from Paul Hartfield.

Figure 308. Amite River in Louisiana near the Mississippi line where a pylon base for a power line was captured by the headcutting of the stream channel. Picture (slide; Image 2036) was taken by Paul Hartfield.

Figure 309. Amite River in Louisiana near the Mississippi line in 1984 in its natural channel before headcutting. Picture (slide; Image 2037) was taken by Paul Hartfield in 1984.

Figure 310. Amite River in Louisiana near the Mississippi line in 1988 at the same spot as in Figure 272 after being degraded by headcutting. Picture (slide; Image 2031) was taken by Paul Hartfield in 1988.

Figure 311. Buttahatchee River before headcutting. Picture (slide: Image 2027) was taken by Paul Hartfield.

Figure 312. Buttahatchee River after headcutting in 1988. Picture (slide; Image 2028) was taken by Paul Harfield in 1988.

Buttahatchee River. The Buttahatchee River is a major tributary of the Tombigbee River in northeastern Mississippi. It supports 37 species of mussels, four of which are federally listed. In the 1970s, the Tennessee-Tombigbee Waterway was constructed, and gravel mines were established near the mouth of the river. Pre– and post-waterway surveys documented a 95% decline in mussel abundance and a 60% decline in mussel diversity in the lower portions of the river. **Figures 311-312** show the Buttahatchee River before and after headcutting upstream from gravel mining operations. **Figures 313-314** show flooded gravel pits along the course of the Buttahatchee River at Hamilton, Mississippi.

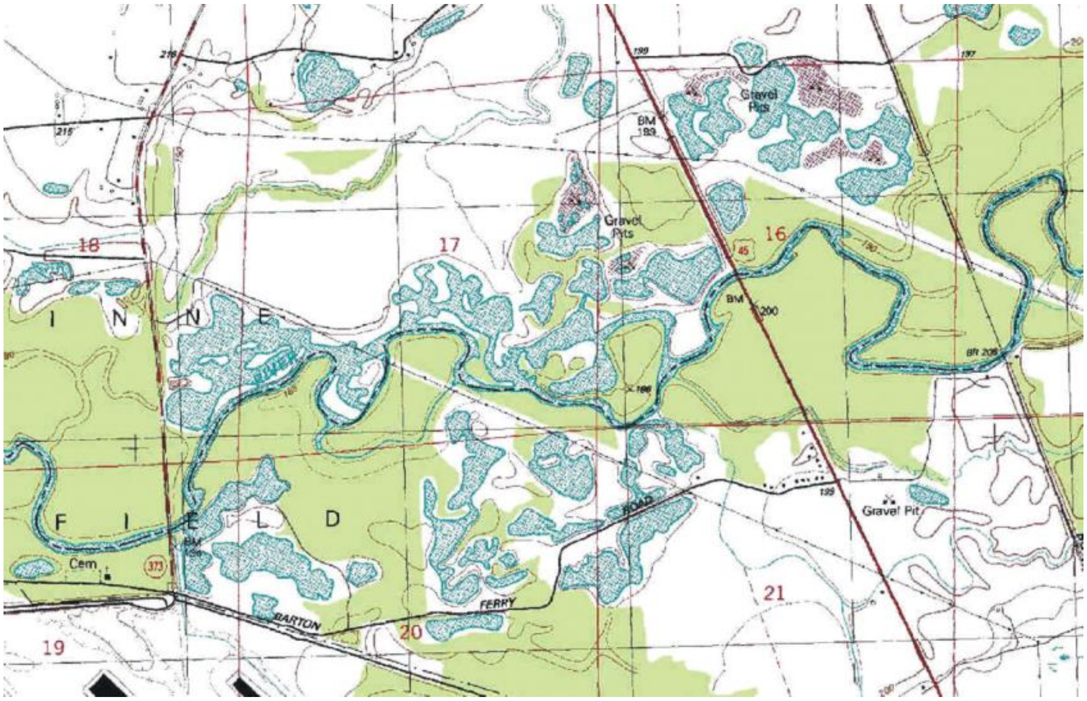


Figure 313. Topographic map of the Buttahatchee River north of the Columbus Air Force Base along the Monroe-Lowndes County Line in Mississippi (Hamilton 7.5-Minute Quadrangle). Flooded gravel pits are shown in blue along the course of the river. Image 2038.

Figure 314. Areal photograph showing flooded gravel pits along the course of the Buttahatchee River along the Monroe-Lowndes County line in Mississippi. Columbus Air Force Base is in the lower left corner of the picture. Image 2039.

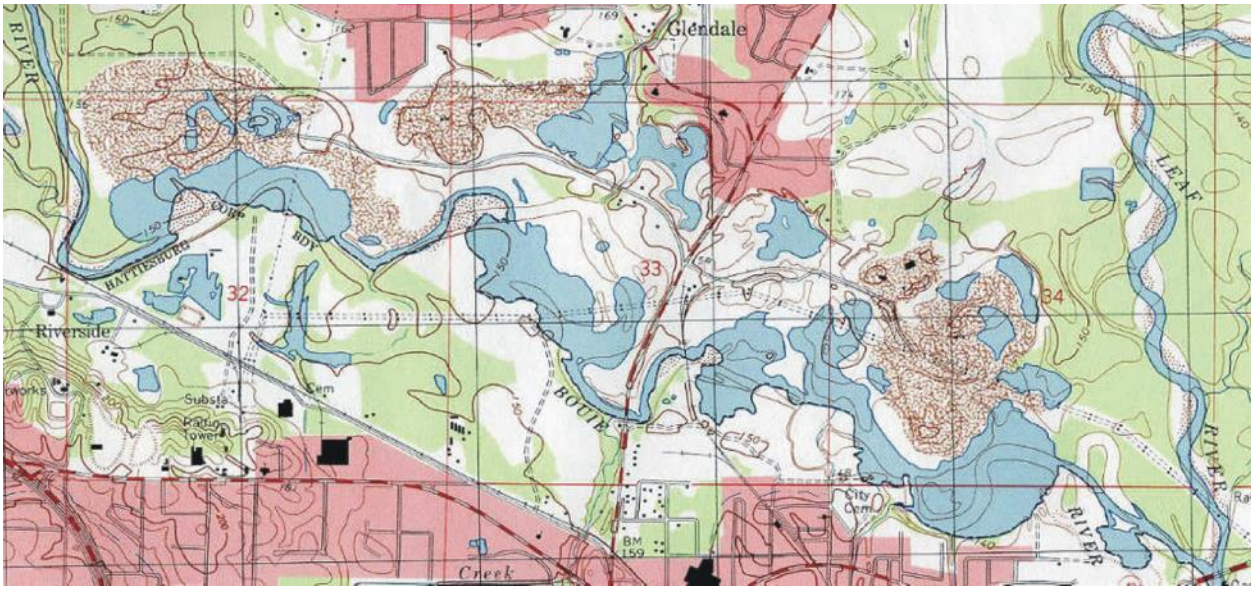


Figure 315. Topographic image (Hattiesburg 7.5-Minute Quadrangle) of gravel mines in the Bouie River near the confluence with the Leaf River north of Hattiesburg, Mississippi. Image 2040.

Figure 316. False color areal photograph of gravel mines in the Bouie River near the confluence with the Leaf River north of Hattiesburg, Mississippi.. Image 2041.

Bouie River. Mossa (2006) quantified the channel planform change in the Bouie River north of Hattiesburg, Mississippi, over the time interval from 1955 (not long after in-stream mining began in the 1940s) to 1996 (just after mining was curtailed by the Mississippi Department of Environmental Quality). **Figures 315-316** show the Bouie River flowing in and out of old gravel pits. Mossa used a series of indices to quantify channel planform changes. These included (see **Figure 317**):

I: Area of channel during the initial period in reach, also equals D + U.

U: Portion of area of channel this is unchanged or remains in same position.

D: Portion of area of channel abandoned/deposited when comparing two periods.

E: Portion of area of channel created/eroded when comparing two periods.

B: Portion of area between channels when comparing two time periods; reflects amounts of displacement from cutoffs, rapid migration, or local avulsions.

Proportional Area Change Ratios

U/I: U divided by I, shows proportion of initial channel area in same position.

D/I: D divided by I, shows proportion of initial channel area abandoned.

E/I. E divided by I, shows proportion of initial channel area eroded or created.

B/I. B divided by I, show proportion of initial channel area between channels.

Ratios of channel change indices can be used to evaluate impacts of floods or specific human activities, such as in-stream mining, on river systems of varying scales (Mossa, 2006). The high E/I values on the lower end of the Bouie River (**Figure 318**, km 12-15), where mining occurred, approaches 5.0, which indicates 400% to 500% increases in the initial channel area over a 41-year interval (Mossa and Coley, 2006). The B/I high value of 1.5 shows an avulsion in the mined reach at km 13.

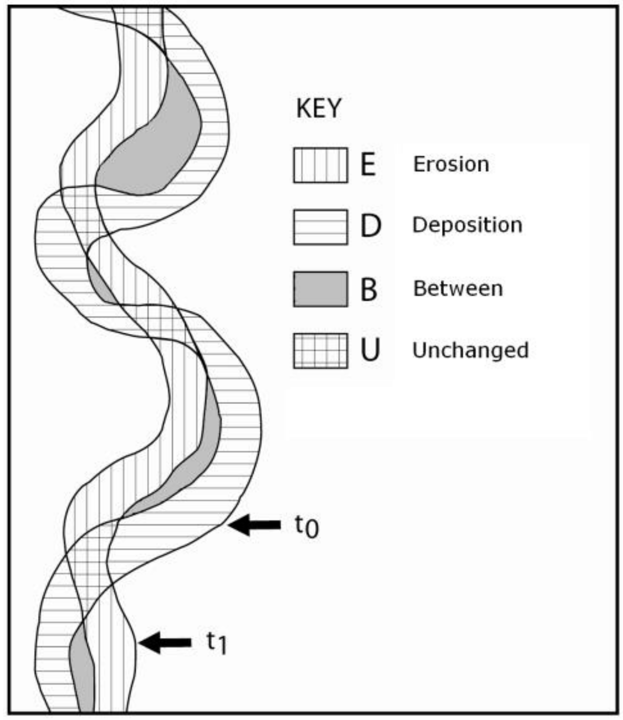


Figure 317. Channel boundaries digitized for different time periods and overlaid in GIS from Mossa, 2006. Resulting polygons are labeled as E, D, B, or U, depending upon the type of change. Image 2042.

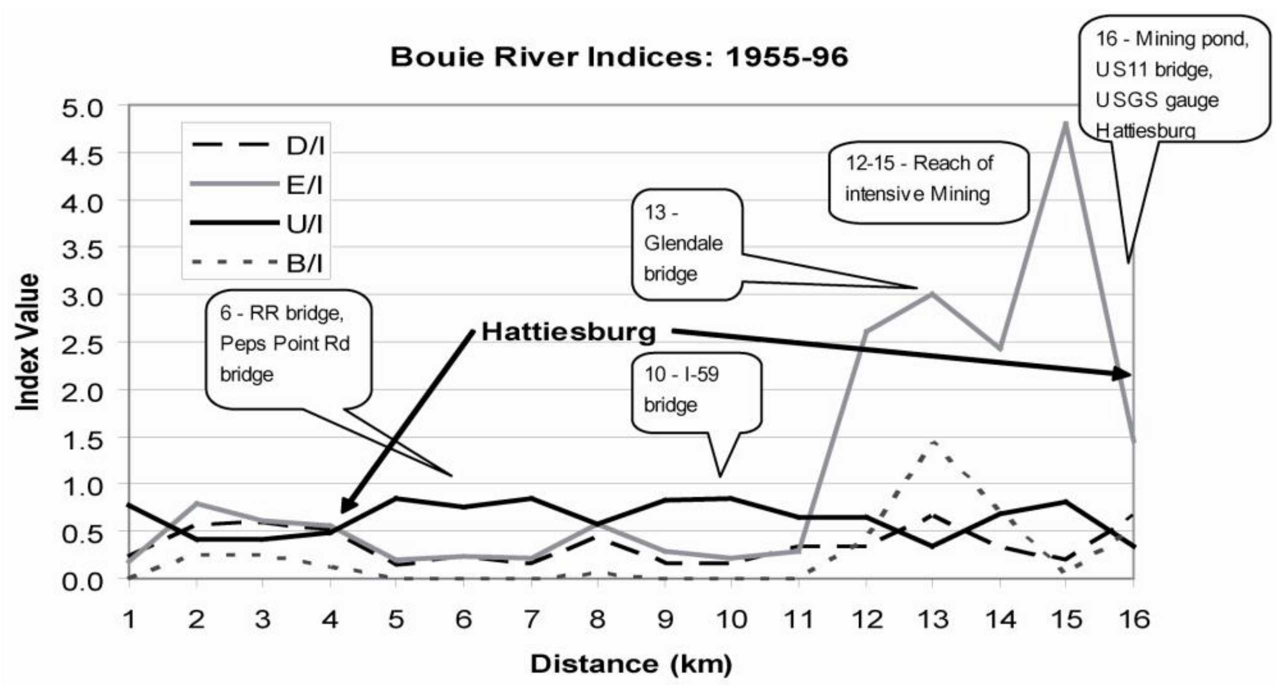


Figure 318. Channel planform change indices along the Bouie River (high E/I values on lower end show massive channel enlargement) (from Mossa, 2006). Image 2043.

Living Streams with Riffles and Pools. Healthy rivers, streams, and creeks are composed off shallows and deeps called riffles and pools. At high flow, the stream is full covering both riffles and pools in deep water. At low flow, especially during droughts, the pools maintain reservoirs of water, which keep aquatic animals alive and provides watering holes for other wildlife. Thus a comparison is made between a living person and a living stream. In this analogy, the electrocardiogram (EKG) waveform of a living person shows the rhythm of a heart beat in which the upward R wave is a stream riffle, and the downward S wave is a pool (**Figure 319**). A flat line with the absence of these waves means death for both a person and the ecology of a stream (**figures 320-322**).

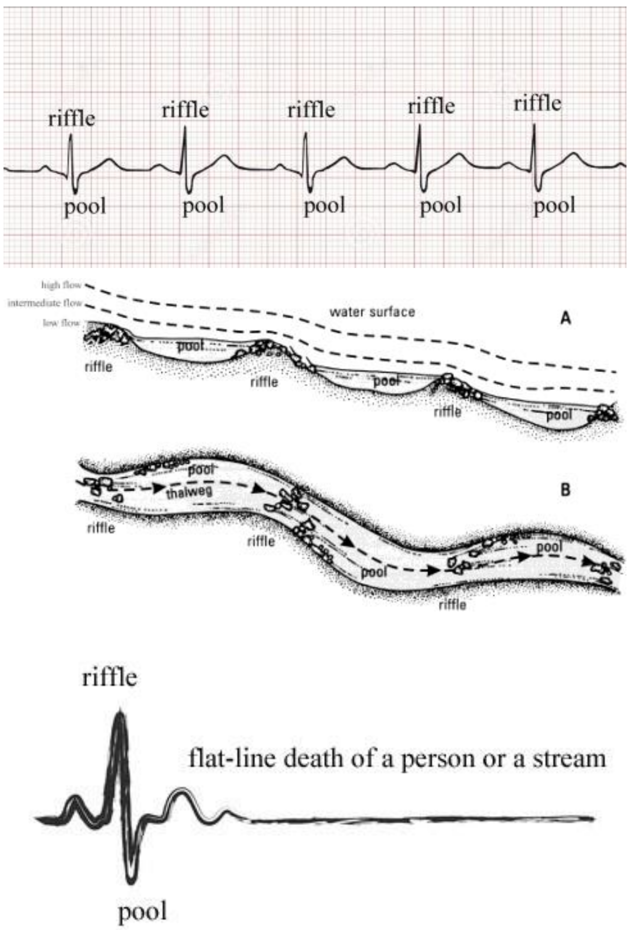


Figure 319. The EKG—riffle and pool analogy. At top is an electrocardiogram of a living person with the upward R wave, labeled riffle, and downward S wave, labeled pool. At middle is a meandering stream with riffles between the pools of the outer meander loops, and a profile, showing water reservoirs in the pools at low flow levels. At bottom is an EKG last heart beat before death and a flat line; a flat-line stream profile is the ecological death of a stream. Image 2535.

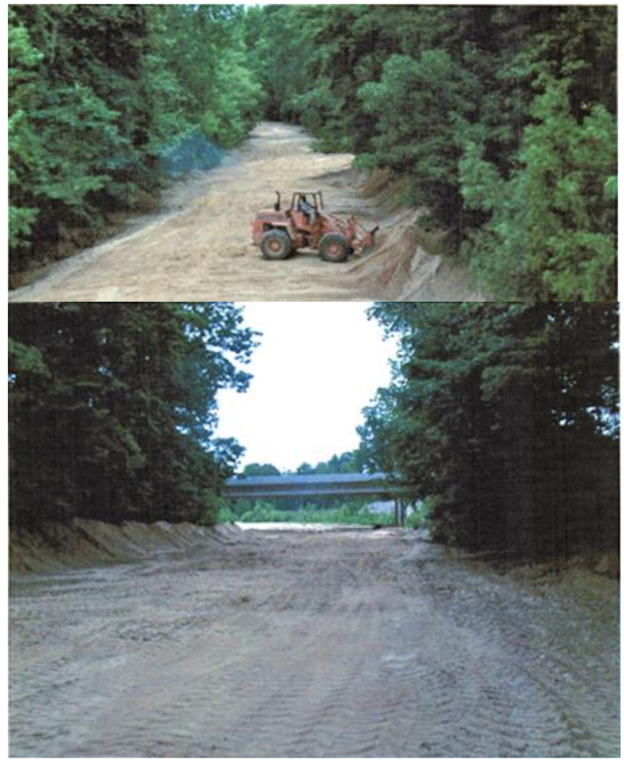


Figure 320. Gravel mining in this stream tributary in west-cental Mississippi has leveled the stream bed to a flat road with no riffles, pools, stream channel, water, aquatic life, or watering holes for wildlife. Image 2015 at top and 2016 at bottom.

Figure 321. An artifical straight channel cut through a mined-out stream in west-cental Mississippi. Image 2012.

Figure 322. A county front end loader mining gravel from the stream of a neighboring county. Image 2010.

Non-Source Point Pollution Remediation

The following account of the remediation of Orphan Creek is from the May 2014 issue of *Environmental News*, pages 3-6 (author not attributed).

Restoring the Biological Integrity of Orphan Creek, A Success Story

Agricultural nutrients, cattle with access to the creek or tributaries, and sediment erosion in pasture land contributed nonpoint source pollution to Mississippi's Orphan Creek. Water quality monitoring conducted in 2001 and 2003 indicated that Orphan Creek was not attaining aquatic life designated use support, which is intended to assure that a water body is healthy enough to support the propagation of fish and wildlife that use the water. As a result, the Mississippi Department of Environmental Quality (MDEQ) added Orphan Creek to the state's 2006 Clean Water Act (CWA) section 303(d) list for aquatic life use impairment.

The Dead Tiger/Orphan Creek Nonpoint Source project significantly reduced sediment and nutrients entering Orphan Creek through the implementation of best management practices (BMPs). After BMPs were installed, biological community data were collected at three monitoring locations on Orphan Creek in 2009. Using the data collected in 2009, Orphan Creek was assessed as attaining aquatic life use support as part of the 2012 section 305(b) statewide assessment process.

Project Highlights

In 2007, MDEQ partnered with the Mississippi Soil and Water Conservation Commission and the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) to implement best management practices (BMPs) within the watershed. BMP installation within the Orphan Creek sub-watershed began in early 2008 and was completed later that year. The BMPs included over 190 acres of nutrient management, nearly 40 acres of pasture and hay-land planting (**Figure 323**), and over 2,800 feet of cattle fencing (**Figure**

Figure 323. Pasture and hay-land planting was necessary in establishing long-term vegetation in order to reduce sediment contribution from highly erosive areas near Orphan Creek. Picture (digital; Image 2498).

Figure 324. Cattle fencing along Orphan Creek was an integral part of creek restoration in areas of heavy cattle influence. The new fencing will keep cattle from being able to gain access to the creek, alleviating direct nutrient loads within the creek. Picture (digital; Image 2499).

324) within the Orphan Creek sub-watershed. After addressing the causes of pollution and demonstrating in-stream improvements within Orphan Creek, BMP installation continued through 2011, comprising a total of 43 BMPs covering 533 acres within the much broader Dead Tiger/ Orphan Creek Watershed (**Figure 325**).

Results

In 2009, MDEQ returned to the original 2001 and 2003 sampling location in Orphan Creek to collect biological community data. The score was 76.5. Data were also collected at two new sites on Orphan Creek and scored 78.9 and 82. The MBISQ was recalibrated in 2008. As a result of the recalibration the threshold for attainment in this region was 66. Using the 2009 data from the original sampling location and the two new sites, Orphan Creek was assessed as attaining the aquatic life use in the 2012 305(b) reporting cycle.

Partners and Funding

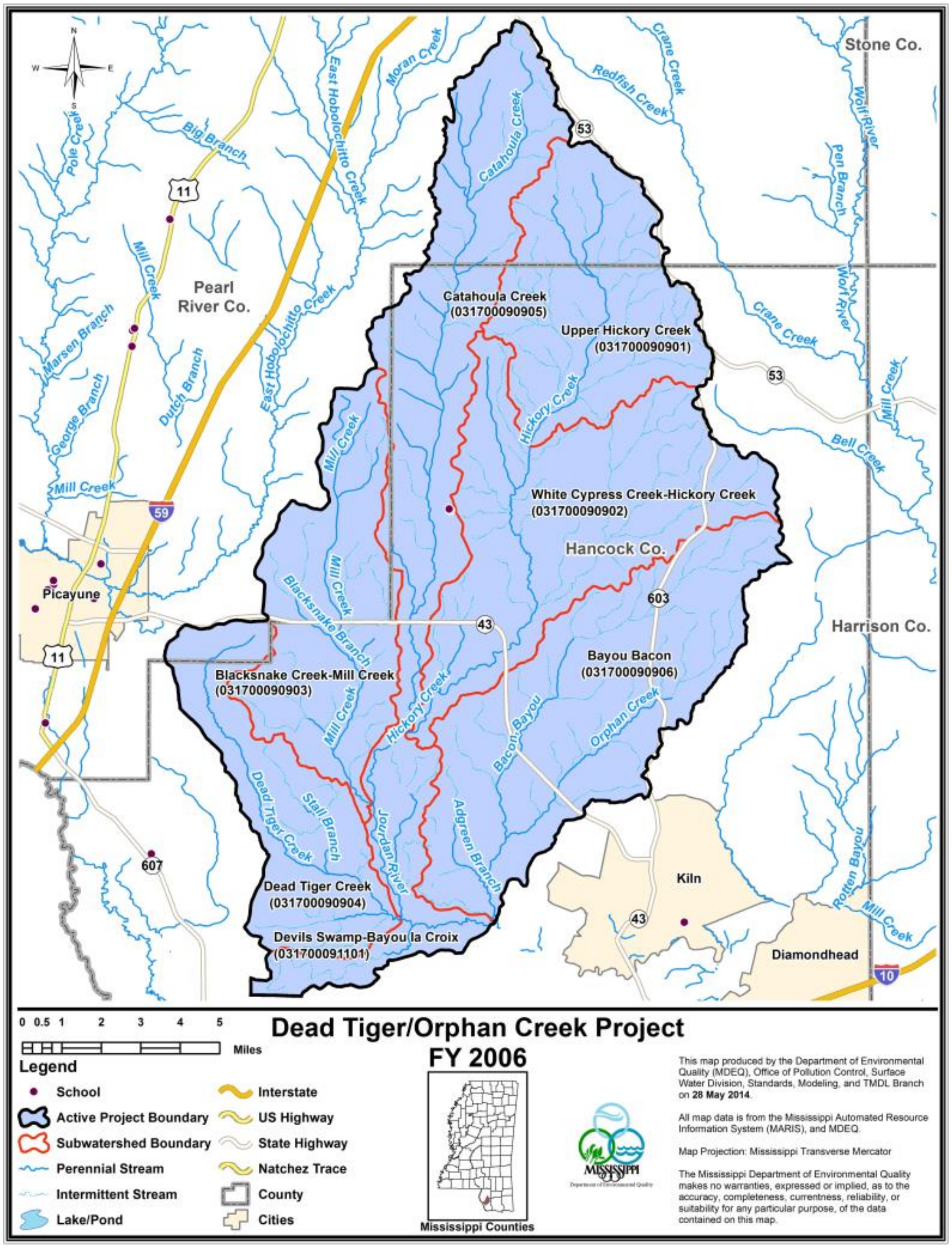


Figure 325. Location of the Dead Tiger Creek and Orphan Creek watersheds. Image 2500.

Due to the high level of stakeholder interest, the restoration of Orphan Creek was a collective effort between the Mississippi Soil and Water Conservation Commission, the Mississippi Department of Environmental Quality, the U.S. Environmental Protection Agency, the NRCS, and the Hancock County Soil and Water Conservation District. The total cost of the overall Dead Tiger/ Orphan Creek Watershed project was $206,779, of which $122,247 was comprised of CWA section 319 funds. Section 319 funds were expended in the following way: $15,319 for technical assistance; $3,273 for education and information outreach; and $103,655 for BMP installation. Participating state and local stakeholders contributed a total of $84,532 towards the implementation of the watershed project.

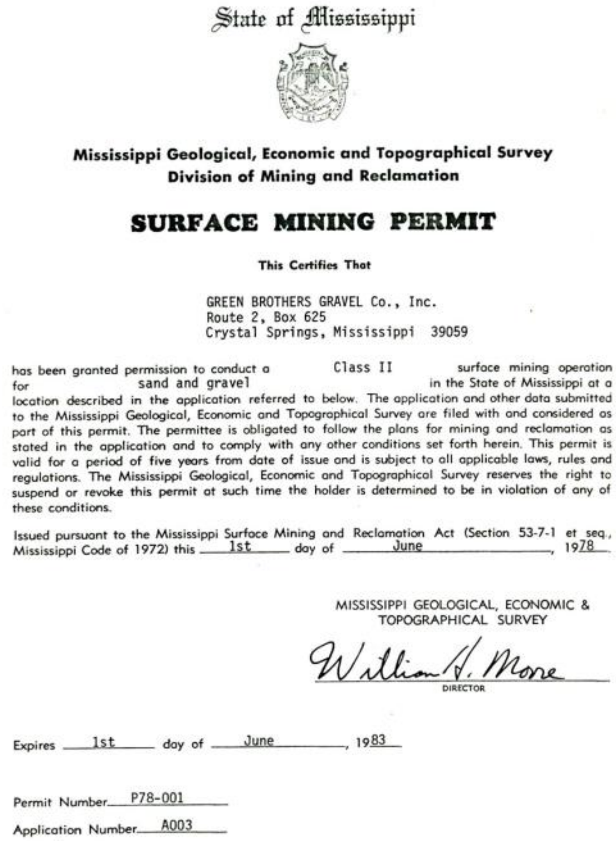
CHAPTER 7. MINES AND MINE RECLAMATION

The First Mine Permit in Mississippi

Thirty Years of Successful Mine Regulation and Reclamation

The following is from the November 2008 issue of *Environmental News* (Bograd and McCarley, 2008, p. 8).

The first surface mining law in Mississippi was passed by the Legislature during the 1977 session, but did not become effective until April 15, 1978. Responsibility for the Mississippi Surface Mining and Reclamation Act was given to the Mississippi Geological Survey (the former name of the MDEQ Office of Geology). Upon passage of the law, Geological Survey staff began writing regulations to implement the law, designing forms, and creating a filing system and other procedures; the latter were set up by Dot Polen. The original team of David Ray Williamson, J. Jackson Harper, and Michael Bograd toured mines throughout the state for sand and gravel, clay, bentonite, limestone, and fill dirt. They also met with industry representatives and held informational meetings for the mining community. Regulations implementing the act were adopted by the Geological Survey Board on October 11, 1977, also effective April 15, 1978.



State of Mississippi

Mississippi Geological, Economic and Topographical Survey
Division of Mining and Reclamation

SURFACE MINING PERMIT

This Certifies That

GREEN BROTHERS GRAVEL Co., Inc.
Route 2, Box 625
Crystal Springs, Mississippi 39059

has been granted permission to conduct a Class II surface mining operation for sand and gravel in the State of Mississippi at a location described in the application referred to below. The application and other data submitted to the Mississippi Geological, Economic and Topographical Survey are filed with and considered as part of this permit. The permittee is obligated to follow the plans for mining and reclamation as stated in the application and to comply with any other conditions set forth herein. This permit is valid for a period of five years from date of issue and is subject to all applicable laws, rules and regulations. The Mississippi Geological, Economic and Topographical Survey reserves the right to suspend or revoke this permit at such time the holder is determined to be in violation of any of these conditions.

Issued pursuant to the Mississippi Surface Mining and Reclamation Act (Section 53-7-1 et seq., Mississippi Code of 1972) this 1st day of June, 1978

MISSISSIPPI GEOLOGICAL, ECONOMIC & TOPOGRAPHICAL SURVEY

William H. Moore
DIRECTOR

Expires 1st day of June, 1983

Permit Number P78-001

Application Number A003

Figure 326. First surface mining permit issued June 1, 1978. Image 2044.

Figure 327. Ken McCarley standing on the edge of the reclaimed first permitted mine in Mississippi, October 3, 2008. The volunteer pines have grown since the revegetation timber was harvested. Picture (digital; Image 2045) was taken on October 3, 2008.

Heyward Carter Green of Green Brothers Gravel Company informed the staff of his intention to apply for the first surface mining permit. His company applied for a five-acre expansion of an existing (grandfathered) mine for sand and gravel in Copiah County. The application was received two days after the effective date of the law, and the first Mississippi surface mine permit (P78-001) was issued on June 1, 1978 (**Figure 326**). The permit was valid for five years, but mining was soon completed. An initial release of 80 percent of the performance bond was granted in 1979, and the final 20 percent of the bond was released on October 13, 1982.

Recently MDEQ Office of Geology staff visited the site of this first permit. Ken McCarley and Michael Bograd were shown the site (**Figure 327**) by Andy Donahoe of Green Brothers Gravel Company. The reclamation remains successful, thirty years after the successful launch of Mississippi's surface mining regulation.

The 1977 Mississippi surface mining law was "progressive" for its time in that it regulated mines for all materials, which other states at that time did not do. As noted in its title, the law emphasized the reclamation of land following mining. Later in 1977 the federal government passed the Surface Mining Control and Reclamation Act (SMCRA), which pertained only to coal and lignite mines. In 1979, the Mississippi Legislature passed the Mississippi Surface Coal Mining and Reclamation Act to remove coal and lignite from the original state law and establish the more stringent requirements for governing coal and lignite mines under federal oversight. In 2002, the mining law was amended to close some glaring loopholes, including mining in streams and being able to start mining after submitting an application for the permit.

Today the Office of Geology administers two surface mining laws, one for coal and lignite mines, and one for sand, gravel, clay, and all other materials that are mined in the state. There are 768 surface mining permits on file covering over 32,000 acres of mining. Annually the Office of Geology sees on average approximately 2,000 acres reclaimed.

---

100 YEAR OLD COAL MINES IN MISSISSIPPI?

The following is from the February 2009 issue of *Environmental News* (Thieling, 2009, p. 12-13).

Many Mississippians are surprised to hear that there is a coal (lignite) mine in Mississippi. It just isn't the kind of thing we think of as being here; maybe Alabama, but not here. There really is a 5,900 acre surface coal mine in Choctaw County, five miles north of Ackerman, and it has been in operation for nearly ten years.

An even greater surprise would be finding out that 100 years ago there were a number of lignite mines around the state. Granted, these mines were very small and short lived, but some did exist.

Because of the poor environmental history of the mining industry in general, and the coal mining industry in particular, beginning in 1977, as part of the Surface Mining Control and Reclamation Act (SMCRA), Congress authorized the Office of Surface Mining Reclamation and Enforcement (OSM) to assess a per-ton production fee on all present-day coal mines. The funds generated by this fee are to be used to reclaim environmental problems at historic coal mines. Historic coal mines are those which existed before 1977 and did not have a reclamation bond under SMCRA.

Mississippi was the third state to gain primacy from OSM under SMCRA, which happened in 1980. Primacy is the authority to regulate coal mining within the state. This authority includes the ability to establish an Abandoned Mine Land (AML) program. Although Mississippi had primacy in 1980, the first coal mining permit was not applied for

Figure 328. A 6' x 8' x 11' deep dry, vertical air shaft at Russell, Lauderdale County. Picture (digital; Image 2046) was taken on October 15, 2008.

Figure 329. Partially flooded underground mine near Louisville, Winston County. Picture (digital; Image 2047) was taken on October 15, 2008.

Figure 330. A 10’ x 11’ x 23’ deep flooded vertical air shaft near Ackerman, Choctaw County. Picture (digital; Image 2048) was taken on October 15, 2008.

until 1997 and issued until 1998. The AML funds generated by production at this mine were reserved for Mississippi by OSM. Mississippi’s AML plan was approved by OSM in September 2007; DEQ received the first AML grant beginning in February 2008. This initial AML grant was to do research and assemble an inventory of abandoned coal mine sites which would be eligible for reclamation by DEQ under this grant.

Publications by the Office of Geology’s in-name predecessors, the Bureau of Geology and the Geological Survey, have published references to lignite in Mississippi as far back as the 1850s. Reports of lignite mining go back to the early 1900s. There apparently was a time in the very late 1800s and early 1900s when a boom period existed for attempts at coal mining within Mississippi. Records from the Department of Archives and History tell a story of a number of somewhat shady “investment” schemes. Unsuspecting investors may have been scammed when promoted and promised mining never materialized. However, a number of legitimate companies did exist and attempted to establish successful, commercial mines. Some of the companies involved include the Mississippi Oil and Gas Co-operative Joint Stock Company, the Meridian Fertilizer Company, and the Gulf, Mobile, & Northern Railroad.

Vertical air shafts into former underground coal mines have been found east of Meridian at Russell and near Ackerman. Much searching has not found the entrance to either of these mines, indicating that they have probably collapsed. Collapse would not be too surprising considering that the “roof” of each mine would have been made of clay, not rock. An underground mine still exists near Louisville. No air shaft has been found, but the entrance to the mine is still open. A part of the mine “roof” at the entrance has collapsed, creating a dam which has trapped rain and ground water, flooding the floor of the mine. The size of these mines is unknown, but all are believed to be small by modern standards, likely less than 1-2 acres. However, at least one was large enough to have been described as using “room and pillar mining,” a common method still used today. One small surface coal mine is well known locally at Reform. Covering about a half acre, it is still used today as a fishing pond.

It is DEQ’s intent, given landowner permission, to reclaim these sites to eliminate hazardous situations (**figures 328-330**). The air shafts are 11 and 23 feet deep with vertical walls. Anyone accidentally falling into one of them would be trapped if they were alone. The remainder of the roof of the mine near Louisville could collapse at any time and crush or trap anyone in it. Fishing in the shallow surface mine near Reform is not planned to be disturbed.

HOUSE CONSERVATION COMMITTEE TOURS THE RED HILLS LIGNITE MINE

The following is, in part, from the September 2009 issue of *Environmental News* (Representative John Mayo, Chairman, House Conservation and Water Resources Committee, 2009, p. 3-4).

The Red Hills Mine recently hosted Chairman John Mayo and the Mississippi House Conservation and Water Resources Committee for a tour of their facility in Choctaw County. MDEQ staff helped coordinate the tour and accompanied the House members. The Office of Geology, housed within MDEQ, is the state agency responsible for regulating the mine. Following is a narrative from Representative Mayo detailing the tour:

The Conservation and Water Resources Committee considers bills on a number of things. Mines and Sewers (separate issues) are two of them.

Recently, the committee took a trip to Mississippi's only currently operating coal mine on 5,900 permitted acres in Choctaw County near Ackerman and 10 miles south of Eupora (**Figure 316**).

I was taken aback by the scope of the project both from a mine the likes of which I have never seen before, and the reclamation processes the company uses to return the land to as near its original topography as possible.

The company operating the mine works on several hundred acres at a time, and as you can imagine it is strip mining. There are six layers of coal in this deposit. Each layer is 1.5 to 4 feet thick and in between layers there may be 10 to 30 feet of dirt that needs to be removed.

Several sedimentation ponds ring the property to capture any run-off water that might get into the nearby streams. These ponds may be disposed of later, but the largest one will be retained as a post-mining recreational pond.

The mine works with OSM, DEQ, and the local land owners to reclaim what they have already mined. When digging out the dirt, the mine separates it into a pile suitable for growing things and another for underlying fill. Where the original land may have been hilly and eroded, the reclaimed land remains hilly, but more gentle slopes are planted with grasses to prevent erosion. The company may, after the grasses take hold, replant the property in whatever was there before. But the landowner also has the option of requiring specific types of trees to be planted. Since this area was all mixed woods, most landowners seem to be opting for loblolly pine. The landowner usually has full access to his land after OSM and DEQ have made their final inspections---about 5 to 8 years after filling the strip back.

The coal mine has a single customer—a coal fired generating plant. On a 24/7 schedule, the plant consumes the equivalent of 110 railroad car loads PER DAY of coal. 160 to 200 ton trucks take the coal from mine to hopper on the edge of the mine. The coal goes from hopper, to conveyor belt, to crushers, to conveyor belt, to furnace. The plant burns the coal at a high temperature, recovers any by products, and sends steam out the smokestacks.

Among the things we were told—truck tires cost $25,000 each. Last year when a worldwide shortage occurred, the company was forced to buy 6 tires for $1.2 million. Some are purchased from China and Russia.

Figure 331. Members of the House Conservation Committee and State Senator Robert Jackson at the Red Hills Mine. Picture (digital; Image 2049) was taken on August 10, 2009.

Figure 332. The length of the lignite mine pit currently opened. Picture (digital; Image xxxx) was taken in 2009. Picture (digital; Image 2050) was taken on August 10, 2009.

Figure 333. Reclaimed land planted in grass and pine trees in the foreground, lignite stock pile in middle, and the pit in the background. Picture (digital; Image 2051) was taken on August 10, 2009.

Figures 331-333 show the members of the committee who went, the drag line, the length of the pit currently opened, and a picture of an area in the foreground that has been reclaimed, in the middle a part being filled in, and the background is the open pit. What is awesome is the dragline is so large, most of us thought it was one quarter to a half mile away from where we stood---it was over a mile and the pit was two miles long. The dragline is electric and (are you ready for this?) powered by AN EXTENSION cord connected to a dedicated substation which buys power from the plant the mine feeds.

Figures 334-340 were taken in 2004 and 2006 and are from *The Geology of Mississippi* (Dockery and Thompson, 2011).

Figure 334. Fault cutting lignite seams at the Red Hills Lignite Mine. Near the top at left, the F seam is against the down-faulted G seam on the right side of the fault. Picture (slide 391-1; Image 20) was taken on November 10, 2004.

Figure 335. Benson Chow (left) and Ken Davis (right) at the 4.0-foot-thick D seam in the Grampian Hills Member of the Nanafalia Formation in the Red Hills Lignite Mine. Picture (color negative 529-20A; Image 338) was taken on September 29, 2004.

Figure 336. View from the western end of the box cut at the Red Hills Mine in Choctaw County. Picture (color negative 530-11A; Image 780) was taken on September 29, 2004.

Figure 337. Distant view of lignite seams in the Grampian Hills Member and the lower Tuscahoma Formation. The J-seam is the top lignite seam at left where it overlies lower Tuscahoma channel sands. The I-seam is the highest lignite seam at right, but this seam is absent at left where channel sands have cut down to the H seam. Seams were labeled by Benson Chow. Picture (color negative 530-28A; Image 84B) was taken on September 29, 2004.

Figure 338. A channel sand in the lower Tuscahoma Formation at the Red Hills Lignite Mine underlies the J seam and, at right, cuts out the I and H2 seams. The G and F seams of the Grampian Hills Member can be seen bending beneath the channel sand where they intersect the ramp ascending from the quarry floor. Picture (slide 393-38; Image 23) was taken on November 10, 2004.

Figure 339. Group picture of RPG field-trip participants on and in front of a haul truck at the Red Hills Lignite Mine; the top of the dredge can be seen in the mine at left. Picture (color negative 597-23; Image 829) was taken on October 7, 2006.

Figure 340. View of the Red Hills Lignite Mine and lignite stock pile from an upper level of the lignite-fired power plant. Picture (color negative 598-1; Image 828) was taken on October 7, 2006.

Figure 341. Reclaimed land from the Red Hills Lignite Mine planted in switchgrass where the mine was in 2004/2005. The active mine can be seen in the distance. Picture (digital; Image 2067) was taken by David Lang in November of 2010.

Figure 342. Tractor mowing hay from the switchgrass planted on reclaimed land at the Red Hills Lignite Mine. Picture (digital; Image 2068) was taken by David Lang in November of 2010.

Figure 343. Moved hay from switchgrass planted on reclaimed land at the Red Hills Lignite Mine where the mine was in 2004/2005. Trees in the distance mark the boundary of the original mine cut. Pine trees on the intervening slope are part of an earlier reclamation. Picture (digital; Image 2069) was taken by David Lang in November of 2010.

A Red Hills Mine brochure entitled *The Coal Hard Facts* places the mine reserves at over 200 million tons of mineable lignite from six seams, varying in thickness from 2 to 6 feet, with an average lignite quality of 5,120 BTU per pound, 43.09% moisture, and 14.40% ash content. In a list of interesting facts are these environmental notes: (1) 2.7 billion gallons of water were collected, sampled, cleaned, and discharged from the mine site in 2004. (2) Over 200,000 trees were planted as part of the reclamation process.

According to Lang et al. (2006), the revegetation sequence consisted of browntop millet and Bermuda grass to provide soil stabilization followed by loblolly pines, or alternately wheat is planted in the cool season to stabilize reclaimed new soil. Initial growth of the loblolly pines is 0.37 to 0.91 meters per year with a survival rate of 70% to 90% after three years. Native grasses reinvaded the reclaimed area from seeds present in the topsoil substitute or wind dispersal as the Bermuda grass declined.

Switchgrass was planted into killed Bermuda grass at the Red Hills Lignite Mine following disking in August of 2008 and replanted on May of 2009 (Lang et al., 2011).

Figure 344. Left: Pine trees planted on reclaimed land at the Red Hills Lignite Mine. The lake at the far left is Pond RP-33-1. Right: Pond R-1 behind a raised area of land that hold the soil from the mine's original box cut. Pictures (digital; Image 2070) from the Mississippi Development Authority website (2011).

Figure 345. Panoramic view of the construction of Pond RP-27-2 on reclaimed land at the Red Hills Lignite Mine. Picture (digital; Image 2071) was taken by Ron Porter on September 15, 2011.

Once established, swtichgrass is an excellent soil stabilizer, but it takes a year to provide adequate ground cover and two years to reach its full potential (**figures 341-343**).

Reclaimed and modified lands at the Red Hill Lignite Mine also include lakes as shown in **Figure 344**. The two ponds labeled RP are reclamation ponds. Ponds in the mine area are shown in **figures 345-349** and are located on the areal photograph in **Figure 350**.

Figure 346. View of Pond P-4-1 through pine trees planted on reclaimed land at the Red Hills Lignite Mine. Picture (digital; Image 2072) was taken by Ron Porter on September 15, 2011

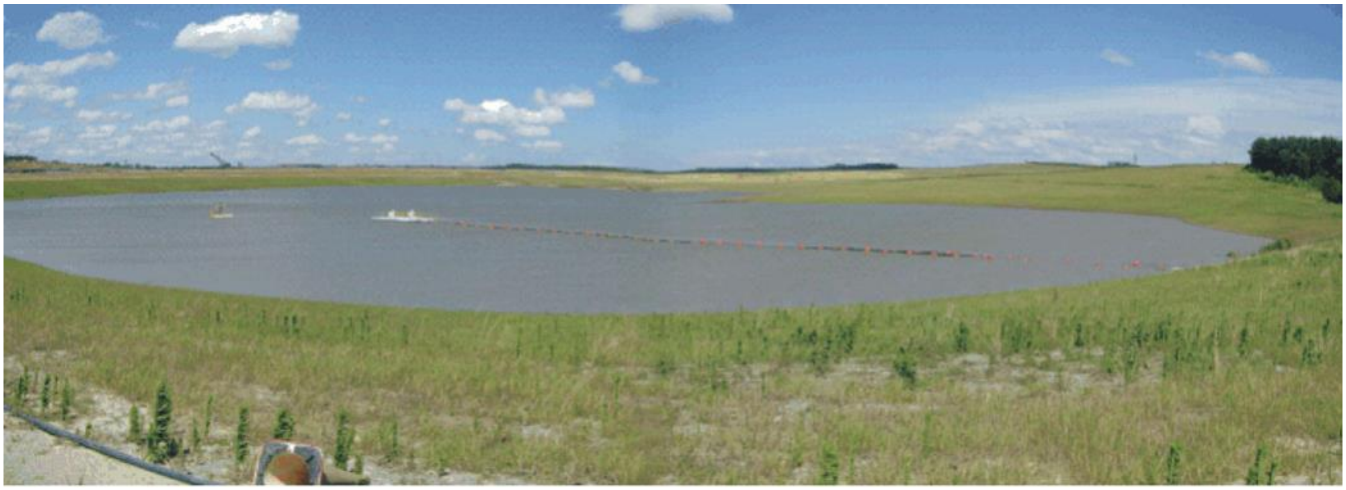


Figure 347. Panoramic view of Pond RP-33-1 on land reclaimed at the Red Hills Lignite Mine. Picture (digital; Image 2073) was taken by Ron Porter on September 15, 2011.

Figure 348. Panoramic view of Pond P-1 at the Red Hills Lignite Mine. Picture (digital; Image 2074) was taken by Ron Porter on September 15, 2011.

Figure 349. Panoramic view of Pond SP-4 at the Red Hills Lignite Mine. Picture (digital; Image 2075) was taken by Ron Porter on September 15, 2011.

Figure 350. Status of land reclamation at the Red Hills Lignite Mine as of October 2011. The blue line is the five year term boundary. The black border line is the permit boundary. The magenta line is the approximate life of the mine disturbance. The red line is the current coal removal limit. The green line is the 29 month prior coal removal limit. The yellow line is the current rough grading limit, and the narrow dark green line is the SPGM respread limit. Ponds are labeled in yellow. Image 2076.

Grandfathered Mines

Mines in operation before the first surface mining law in Mississippi became effective on April 15, 1978, were exempted under a grandfather clause. One of those mine was the Vulcan Materials Company's Iuka limestone quarry in Tishomingo County. Limestone riprap from this quarry was used in the construction of the Tennessee-Tombigbee Waterway, much of which lines the waterway's shores through the divide cut in Tishomingo County. Only newly mined acreage after 1978 in the Iuka quarry was covered under the reclamation law. The final release of the mine's performance bond requirement was completed in July of 2002.

The Iuka quarry was excavated as a rectangular box cut in the flood plain of Cripple Dear Creek about a mile west of the Alabama state line, and the quarry floor extended some 150 feet below the level of the flood plain. The creek was diverted around the quarry, and spring water from the Tuscumbia Limestone in the high walls was pumped from the lower quarry to the surface. When the quarry was abandoned, it was flooded by the waters of Cripple Dear Creek, thus making it the state's deepest lake. **Figures 351-352** show the height of the quarry's high wall and give evidence of the depth of the lake that now occupies the quarry.

Figure 351. Paleo-sinkhole in the Tuscumbia Limestone at the Vulcan Materials Company's Iuka quarry in Tishomingo County. Sediment filling the sink hole has spilled over the quarry wall, making a pile to the upper right of the truck on the quarry floor. Picture (color negative 419-8; Image 382) was taken on May 8, 1989.

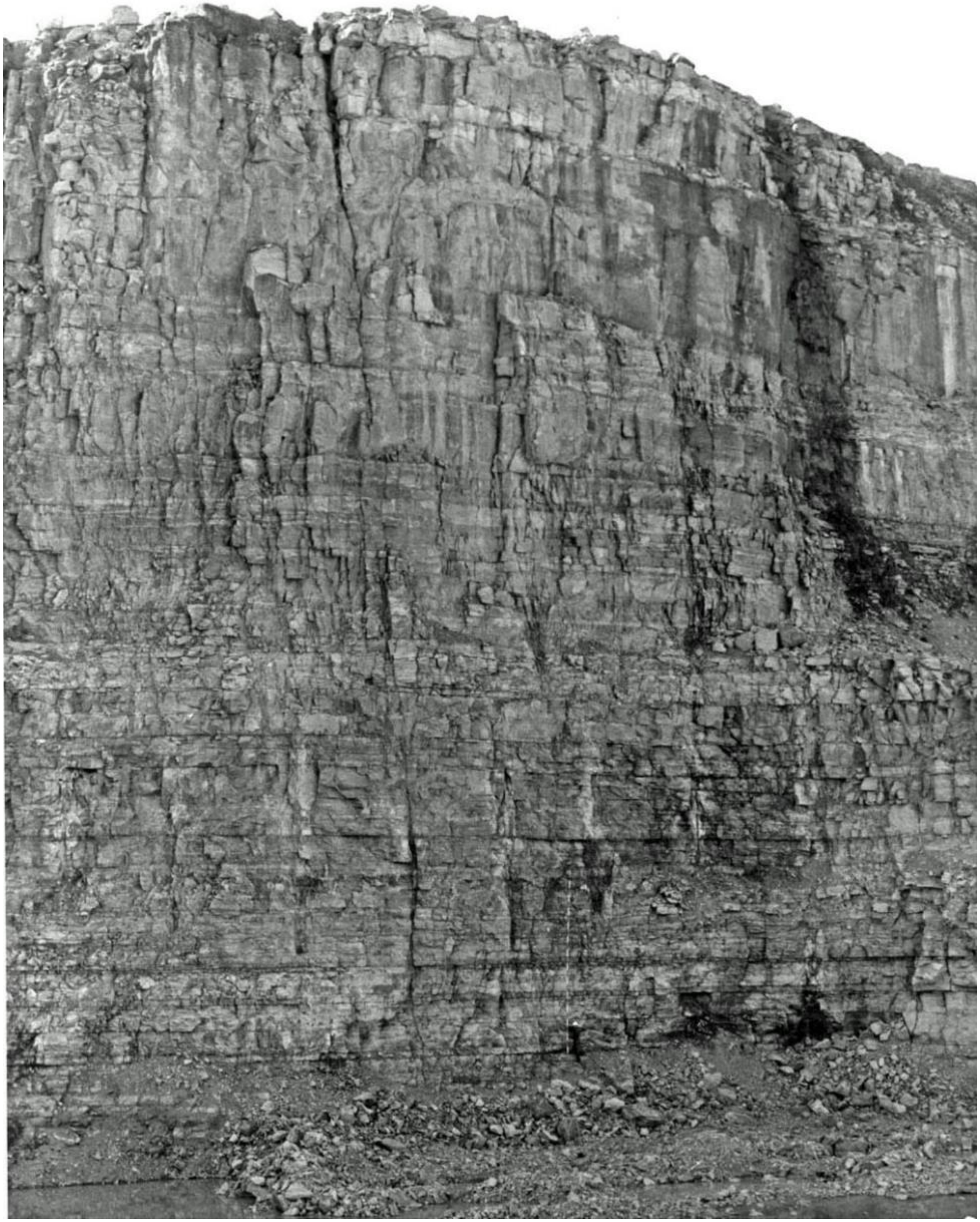


Figure 352. High wall (southwest wall) of the Vulcan Materials Company's Iuka limestone quarry in Tishomingo County. Bob Merrill is holding a 25-foot-high survey rod at the base of the wall. Picture (scanned print; Image 1450) is from Merrill (1988, p. 54).

CHAPTER 8. SOLID WASTE DISPOSAL

The following information is from the *Status Report on Solid Waste Management Facilities and Activities, Calendar Year 2010* prepared by the Solid Waste Policy, Planning & Grants Branch of the Office of Pollution Control, Mississippi Department of Environmental Quality (MDEQ). MDEQ develops a status report each year to provide information on solid waste management activities for the year. This report contains information on disposal activities conducted at each landfill, rubbish site, and land application site in the state as provided by law from the facility owner. This report also includes information from beneficial determination holders on the distribution of industrial and other by-products for legitimate end uses, and information from waste tire haulers, collectors, and processors regarding the quantities of waste tires managed.

Part I of the Solid Waste report concerns commercial solid waste disposal facilities. Such facilities are defined as "any facility that is engaged in the disposal of solid waste for compensation or which accepts waste from more than one generator not owned by the facility owner." These facilities include:

1. Municipal Solid Waste (MSW) Landfills
2. Non-Municipal Solid Waste (Non-MSW) Landfills
3. Class I and Class II Rubbish Sites

During Calendar Year 2010, a total of 6,482,592 tons of solid waste was received at commercial and non-commercial landfills and rubbish sites. The total solid waste was divided among the various categories into the following percentages and amounts: commercial landfills 51.28% (3,324,298 tons), non-commercial landfills 31.02% (2,010,587 tons), non-commercial rubbish sites 17.22% (1,116,455 tons), and commercial rubbish sites 0.48%(31,252 tons) (**Figure 353**). Of the amounts given above, Mississippi received a total of 732,780 tons of solid waste from out-of-state sources, representing 11.30% of the total solid waste for 2010.

Municipal Solid Waste (MSW) Landfills

MSW landfills are designed and constructed to receive a wide range of nonhazardous solid wastes, including household garbage, commercial business wastes, nonhazardous industrial waste, and special wastes such as asbestos or treated medical waste. There were 19 MSW landfills in Mississippi (in 2010). These landfills are sited in geologic formations with low permeability and sufficient thickness to protect groundwater resources from leachate contamination. Suitable geologic units include the upper clay-rich intervals of alluvial fills (i.e. the Delta and coastal area), Miocene clays, the Yazoo Clay, clays in the Wilcox Group, the Porters Creek Clay, and the Selma Chalk (and marl). **Figure 354** shows the location of the state's 19 MSW landfills on the state geologic map.

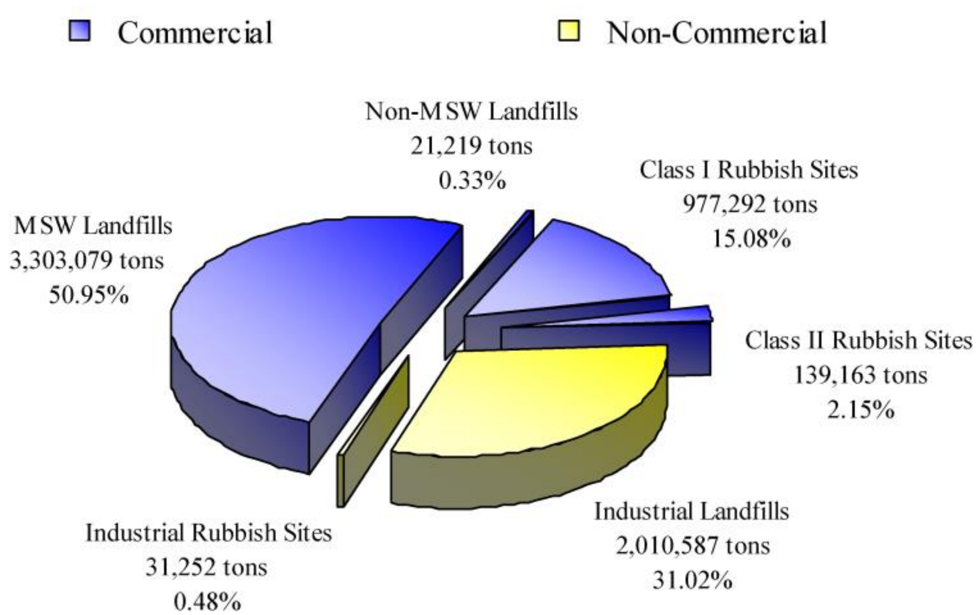


Figure 353. Amount of solid waste disposed in various landfill categories in Mississippi, from Mississippi Department of Environmental Quality, Status Report on Solid Waste Management Facilities. Calendar Year 2010. Image 2077.

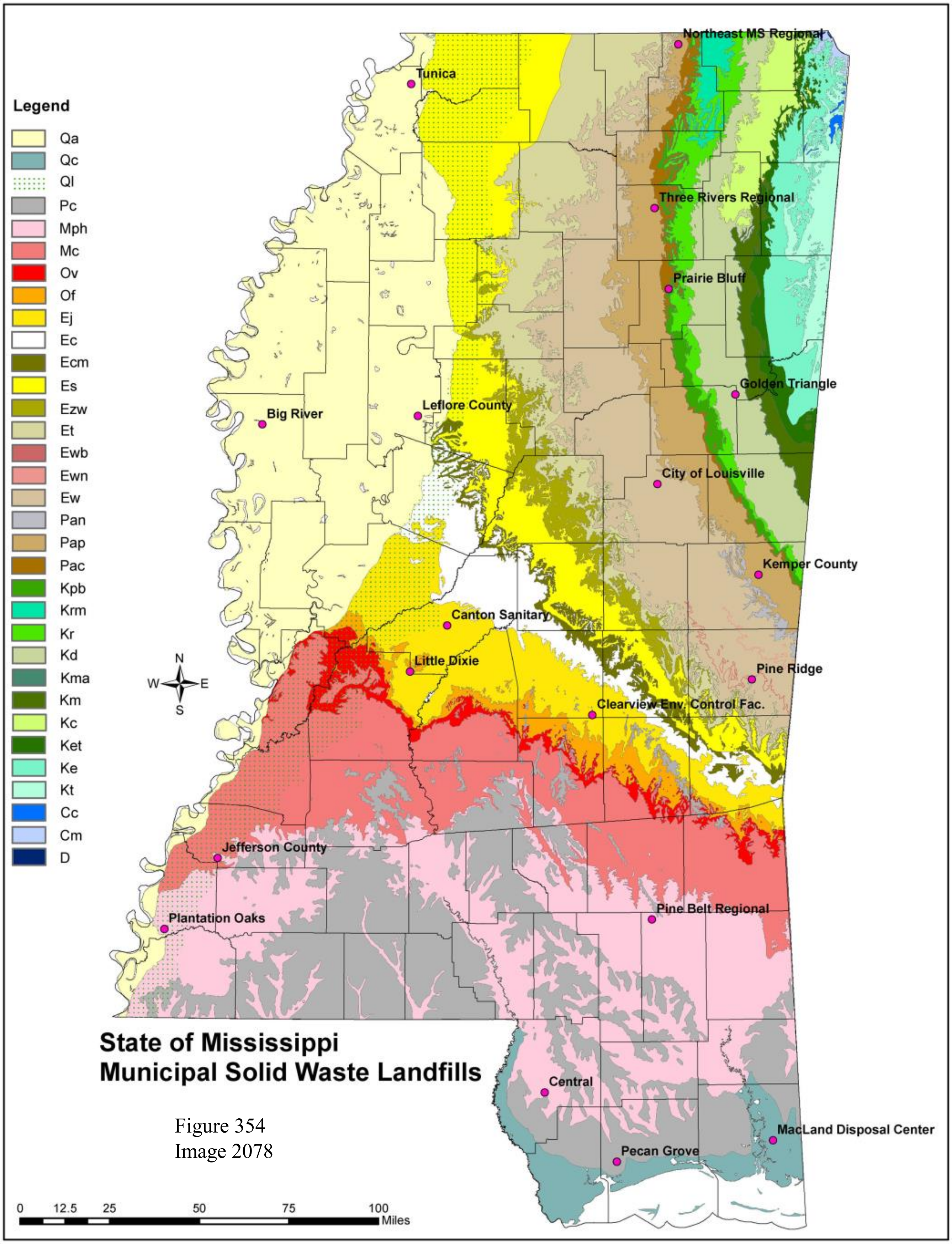


Figure 354
Image 2078

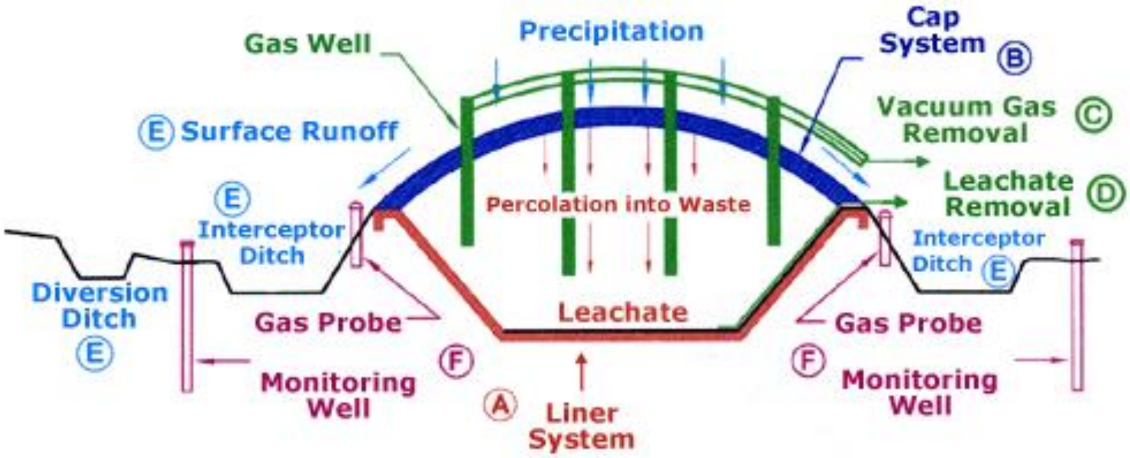


Figure 355. Typical landfill schematic by Martin & Martin, Inc., used in the Pennsylvania Waste Industries Association (A Chapter of the National Solid Waste Management Association) website. Image 2079.

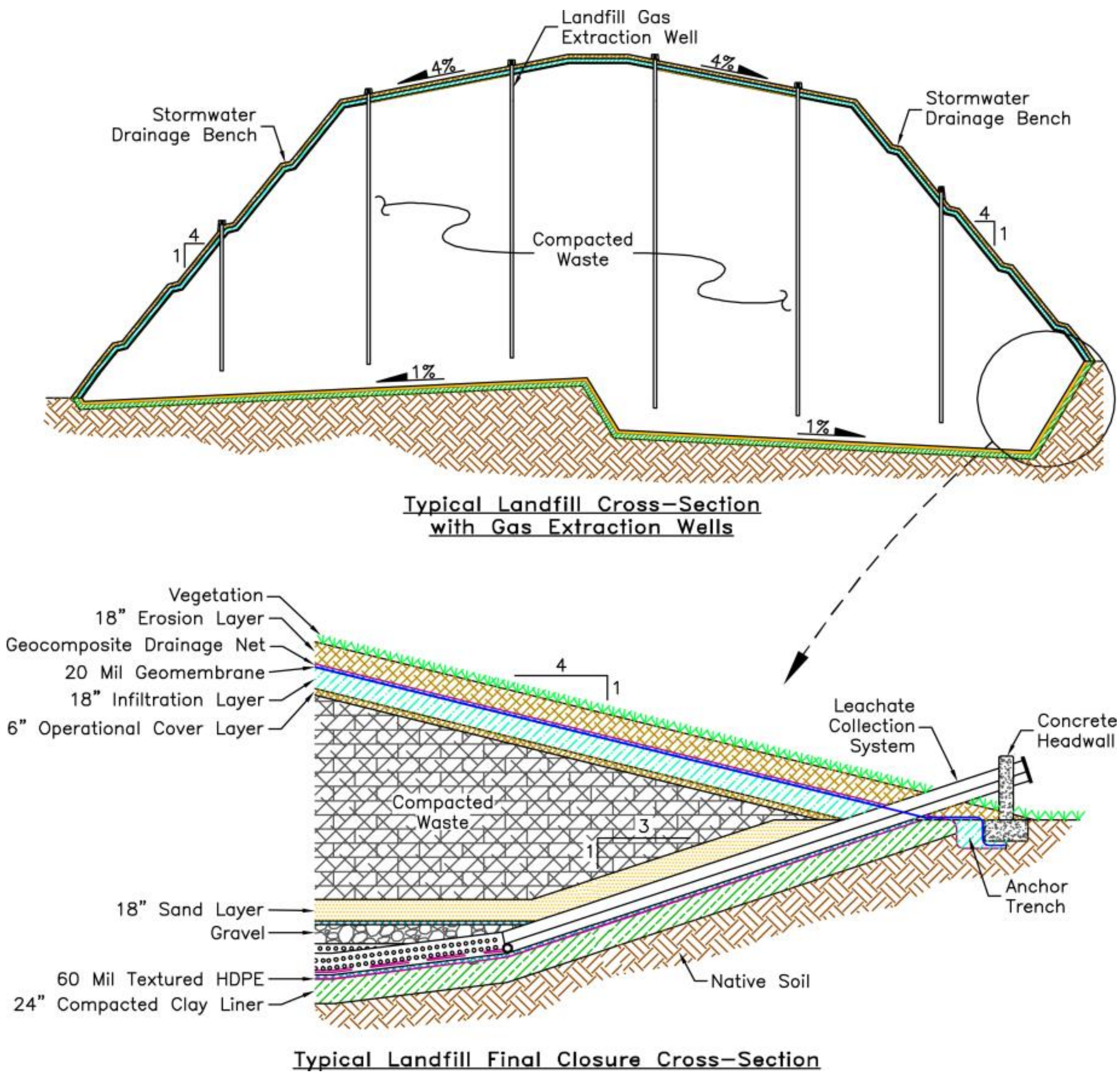


Figure 356. Landfill design for the Three Rivers Regional Landfill on the Porters Creek Clay near Pontotoc, Mississippi. Picture (digital; Image 2080) from Jeff Allen, President of Eco-Systems, Inc.

Figure 357. Little Dixie Landfill weighing station (left) and leachate storage (right). Picture (digital; Image 2081) was taken on October 30, 2011.

Figure 358. Leachate storage and treatment ponds at the Little Dixie Landfill. Picture (digital, Image 2082) was taken on October 30, 2011.

Figure 359. Little Dixie Landfill whirlwind illustrates the dust potential from strong winds. Picture (digital; Image 2083) was taken on October 30, 2011.

Figure 360. Covering garbage at the Little Dixie Landfill. Picture (digital; Image 2084) was taken on October 30, 2011.

Figure 361. Distant view of the downtown Jackson skyline from the Little Dixie Landfill. Picture (digital; Image 2085) was taken on October 30, 2011.

Figures 355-356 show landfill designs for Municipal Waster Landfills such as the following three examples in Mississippi: (1) Little Dixie Landfill (**figures 357-361**), (2) Clearview Landfill (**figures 362-364**), and (3) Prairie Bluff Landfill (**figures 340-342**) . Besides the state's 19 Municipal Waste Landfills, the state has 6 Non-Municipal Solid Waste Landfills.

The Little Dixie Landfill in southern Madison County services the Jackson metro area in Hinds, Madison, and Rankin counties, and receives (in 2010) solid waste from some 30 other counties, including Prentiss County in northeastern Mississippi. The landfill is underlain by a 400-foot thick section of Yazoo Clay. Elevations at the landfill provide spectacular vistas of the surrounding terrain, including a view of downtown Jackson (**Figure 346**).

Figure 362. Fossil whale excavation (foreground) at the Clearview Landfill (active landfill in background) in Scott County. Picture (color negative 495-24; Image 2086) was taken on September 6, 2002.

Figure 363. Fossil whale excavation (foreground) at the Clearview Landfill, and a large dump truck unloading garbage (background). Picture (color negative 495-30; Image 2087) was taken on September 6, 2002.

Figure 364. Fossil whale excavation in the Yazoo Clay at the Clearview Landfill. The skull and lower jaw are in the upper right, and the rib cage, with 38 pairs of ribs, is in the middle. Composite picture (color negatives 488-18 [right] and 488-17 [left]; Image 2088) were taken on August 20, 2002.

The Clearview Landfill in Scott County serves east-central Mississippi and the Jackson metro area. In 2010, the landfill received solid waste from some 40 counties in Mississippi. The landfill rests above a 300-foot-thick section of the Yazoo Clay and was the site of a fossil whale excavation in August and September of 2002 (**figures 347-349**).

The Prairie Bluff Landfill in Chickasaw County serves northern Mississippi and received solid waste from 38 counties in 2010. The landfill is contained within a 70-foot-thick section of chalky marls in the Prairie Bluff Formation. **Figure 365** shows the gray marls of the Prairie Bluff Formation outside the containment wall for the landfill. **Figures 366** and **3** show the landfill's ten thousand gallon leachate holding tank. **Figure 367** shows the label on the holding tank, warning of possible dangerous levels of methane.

Class I and Class II Rubbish Sites

Class I and Class II rubbish sites receive a subset of the overall municipal solid waste generated in the state that includes non-putrescible types of waste. This type waste is subject to less strenuous requirements and does not necessarily involve the collection of leachate and methane gas. In 2010, there were 82 permitted commercial class I rubbish sites, 8 of which were inactive, and 70 permitted commercial class II rubbish sites, 13 of which were inactive. For that year, a total of 977,292 tons of rubbish was disposed in class I site and

Figure 365. Containment levee (at left) for the Prairie Bluff Landfill (far left) in Chickasaw County. At right is the gray chalky marl of the Prairie Bluff Formation for which the landfill was named. This landfill receive solid waste from 35 counties in 2010. Picture (digital; Image 1052) was taken on August 23, 2007.

139,163 tons were disposed in class II rubbish sites.

Class I rubbish sites may accept the following:

1. Construction and demolition debris
2. Brick, mortar, concrete, stone, and asphalt
3. Cardboard
4. Natural vegetation
5. Appliances which have had the motor removed (excluding refrigerators and air conditioners)
6. Furniture
7. Plastic, glass, crockery, and metal (excluding containers)
8. Sawdust, wood shavings, and wood chips

Class II rubbish sites may accept limited types of inert rubbish, including:

1. Natural vegetation
2. Brick, mortar, concrete, stone, and asphalt

Class I and class II rubbish site often start out as a sand, gravel, or borrow pit before being permitted as disposal areas. Converting an existing pit into a permitted rubbish site eliminates the expense of mine and increases the duration of site activity and revenue. Also, a rubbish site that commences as a small, locally owned operation may be sold to a large corporation, likely increasing the volumes of waste and related traffic.

Figure 366. Ten thousand gallon leachate holding tank at the Prairie Bluff Landfill. Picture (digital; Image 2089) was taken on August 23, 2007.

Figure 367. Warning label on the Prairie Bluff Landfill leachate holding tank. The warning is placed because leachate can produce a dangerous/deadly concentration of methane gas. Picture (digital; Image 2090) was taken on August 23, 2007.

Ideally, landfills and rubbish sites protect the environment from the large volume of solid wastes generated on the local, state, and national level. To imagine a world without landfills, consider a garbage strike in a large city and the piles of putrid garbage that collect along the streets. Commerce would cease without a proper place to dispose our waste materials. Nevertheless, landfills and rubbish sites can cause problems for those that live nearby.

Figure 368. Poorly secured load of natural vegetation headed up a winding road to the dump. Such loads drop debris and cause traffic hazards. Picture (color negative 436-13; Image 2096) was taken on March 18, 1998.

Figure 370. Collision avoided as minivan passes between debris-laden dump truck and oncoming pickup truck on Pinehaven Road in Clinton, Mississippi. Picture (digital; Image 2101) was taken on August 3, 2011.

These problems are minimized when operations are optimally sited and well-managed. Practices to monitor and pickup associated roadway debris can alleviate tensions with local residents. Uncontrolled and poorly managed landfills and rubbish sites can cause a myriad of environmental problems (**figures 353-362**), including the following:

1. Heavy commercial traffic on local roads, including eighteen-wheelers with waste.

2. Falling debris from trucks and trailers. Haulers should cover their loads, but sometimes do not (**figures 368-371**).

Figure 369. Minivan dodges newly fallen debris from the dump truck ahead, then swerves back into its lane to miss an oncoming pickup truck. Picture (digital; Image 2100) was taken on Pinehaven Road in Clinton, Mississippi, on August 3, 2011.

Figure 371. Dump truck, using sheet rock as extended side boards, drops debris along Pinehaven Road in Clinton, Mississippi. Wind can easily lift sheet rock from a truck bed at road speeds of 40 to 50 miles per hour. Picture (digital; Image 2102) was taken on August 3, 2011.

3. Frequent flat tires from roofing tacks, nails, screws, and other sharp objects.

4. Destruction of local road surfaces from heavy truck traffic.

5. Liquid waste draining from poorly maintained truck beds.

6. Unauthorized offsite and nearby dumping from those who miss the closing hour or find that the facility will not accept their refrigerator or air conditioner.

7. Noise pollution similar to the sound of an ongoing construction site.

8. Inadequate dust control.

9. Uncontrolled sediment runoff and erosion, potentially affecting adjacent landowners (**figures 372-374**).

10. Inadequate odor control from uncovered solid waste (**figures 375-377**).

Figure 372. MDEQ personnel view sediment runoff at a class I rubbish site, which entered local streams. Picture (color negative 438-21; Image 2091) was taken on April 21, 1998.

Figure 373. Lofty view above a class I rubbish site, demonstrating eroded gullies and absent controls for adequate storm water and sediment runoff. Picture (color negative 438-24: Image 2092) was taken on April 21, 1998.

Figure 374. Uncontrolled sand deposition from a rubbish site into a creek ravine that was formerly a clay-bottom. Picture (color negative 436-12; Image 2093) was taken on March 18, 1998.

Figure 375. Construction debris at a class I rubbish site. Picture (color negative 438-20; Image 2094) was taken on April 21, 1998.

Figure 376. Sheet rock is common at rubbish dumps. Picture (color negative 438-19; Image 2095) was taken on April 21, 1998.

Figure 377. A thick layer of debris on a landfill slope. Picture (color negative 436-7; Image 2097) was taken on April 21, 1998.

Oil and Gas Well Blowouts

The following is, in part, from the December 2011 issue of *Environmental News*, (Dockery and Thompson, 2011, p. 14-18: Mississippi Technology that killed BP's Deepwater Horizon/Macondo Blowout Well).

BP's leased Deepwater Horizon mobile offshore drilling rig, which had just completed drilling the BP Macondo well in the Gulf of Mexico, suffered a catastrophic blowout around 9:45 p.m. CDT on April 20, 2010, after high-pressured methane gas pushed up the drill column and exploded on the platform. Efforts by multiple ships to extinguish the flames were unsuccessful (**Figure 378**), and, after 36 hours on fire, the rig sank on the morning of April 22, 2010. That afternoon, oil was spotted on the ocean surface above the sunken rig. Early reports minimized the magnitude of the oil spill, but the final estimate for the leak was 62,000 barrels per day, decreasing to 53,000 barrels per day just before the well was capped on July 15, 2010. According to the Flow Rate Technical Group, the spill amounted to about 4.9 million barrels of oil, which made it the largest oil spill ever to originate in U.S. controlled waters and the largest in the Gulf of Mexico (**Figure 379**).

Figure 378. Fire on the mobile offshore drilling unit Deepwater Horizon is battled by platform supply vessels. This picture was taken by the crew of a Coast Guard MH-65C Dolphin Rescue helicopter on April 21, 2010. Image 2109.

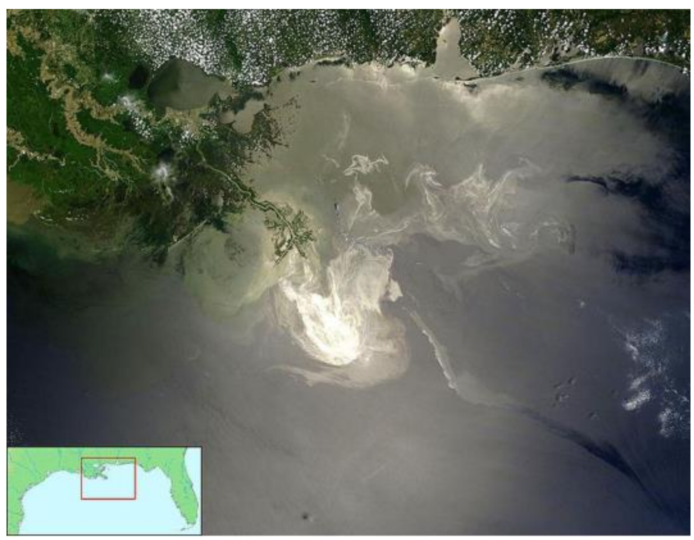


Figure 379. Picture from NASA's Terra satellite of the Horizon oil spill on May 24, 2010. The spill is illuminated by sunlight. The oil slick smoothes the ocean surface, making the sunlight brighter on the slick than the surrounding ocean. Image 2110.

Submarine robots and new technologies were tested in the efforts to cap the well head at a water depth of 5,000 feet. Initial efforts by remotely operated underwater vehicles to close the blowout preventer valves on the well head failed, as did the emplacement of a 125-tonne (138 ton) containment dome, which was soon clogged by gas hydrates. Attempts to kill the well by pumping heavy drilling fluids into the blowout preventer as a "top kill" were unsuccessful. However, the positioning of a riser insertion tube into the burst pipe was successful enough to collect some 22,000 barrels of oil at the surface aboard the drillship Discover Enterprise. The ultimate solution came from a cap consisting of a Flange Transition Spool and a 3 Ram Stack. On July 15, BP successfully tested this cap against the full force of the gusher. Mud and cement were later pumped through the new well head to reduce the pressure inside it and to provide a temporary stop to the flow of oil.

The permanent kill for the BP well came from two relief wells drilled on each side of the leaking Maconda well. These wells were drilled vertically to a specified depth and then directionally to intercept the well casing and fill it full of cement. This was accomplished using proven well interception technologies, technologies that were first developed and successfully used in an onshore blowout in Mississippi. Transoceans's Development Driller III began drilling a relief well on May

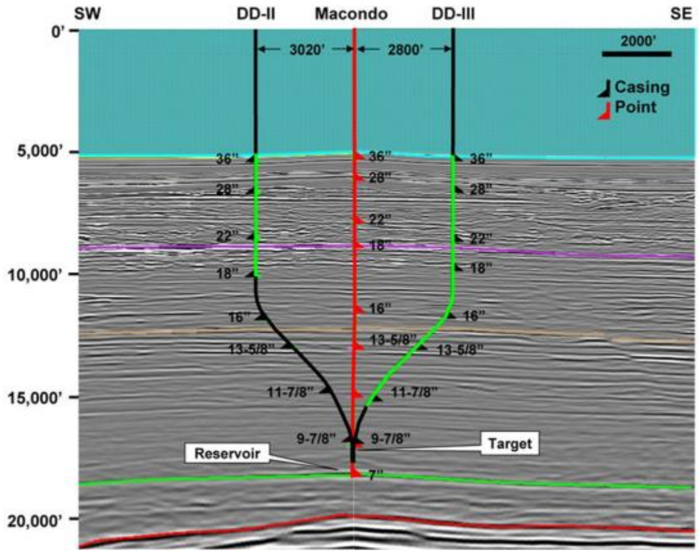


Figure 380. The Development Driller III and Development Driller II relief wells' progress in intercepting the annulus of the Macondo well. Picture is from a slide presentation by BP executive Ken Wells in a technical-update on June 28, 2010. Image 2111.

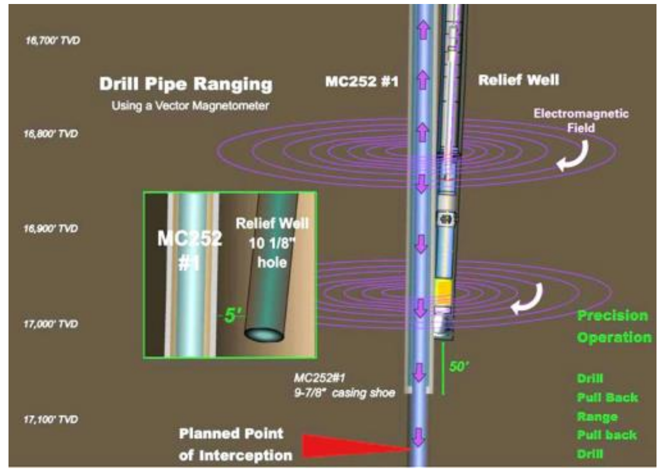


Figure 381. Diagram of the Developer Driller III relief well closing in on the annulus of BP's Deep Horizon/Macondo well. Picture is from the last slide presented by BP executive Kent Wells in a technical-update briefing on June 28, 2010. Image 2112.

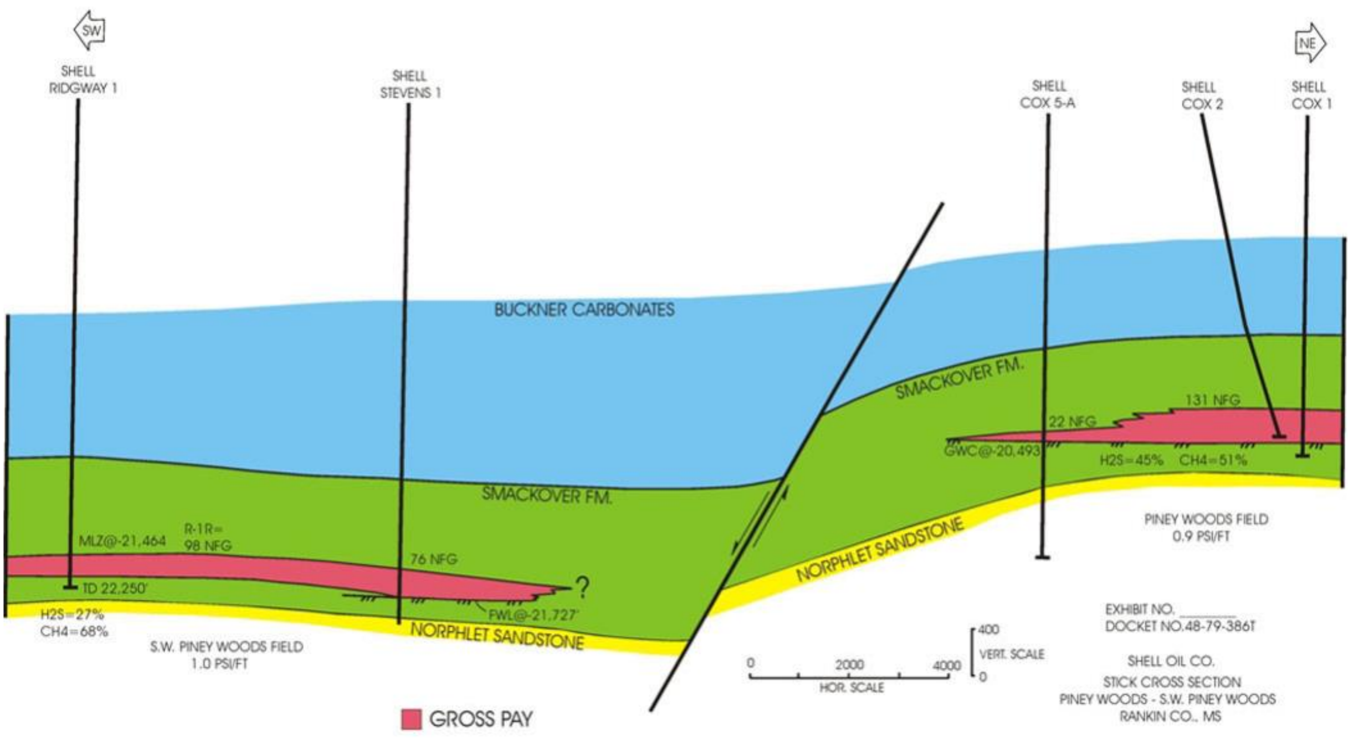


Figure 382. Cross section of the Piney Woods (right) and Piney Woods Southwest (left) gas fields. The gross pay zone contains over-pressured gas of about equal mixtures of methane and hydrogen sulfide in sandstones within the Smackover Formation. The Cox No. 1 blowout well is at the far right. Next to it is the Cox No. 2, which was later drilled as a development well. This cross section is modified from one provided by Julius Ridgway. Image 2113.

2, 2010; the GSF Development Driller II followed with a second relief well on May 16 (**Figure 380**). The first relief well reached its total depth at about 18,000 feet on September 16, 2010 (**Figure 381**), and began pumping cement into the well bore. By September 19, the BP Maconda well was effectively killed.

The first successful use of a relief well to intercept the annulus of a blowout well occurred in southwestern Mississippi's over-pressured Deep Smackover Gas Trend in 1970. After being successfully drilled to core depth, the Shell Oil Corporation Cox No.1 at Piney Woods in Rankin County, Mississippi, a deep Smackover exploratory well, surprised geologists with high-pressured, sour gas in the Jurassic at 21,122 feet (**Figure 382**). Sour gas, or hydrogen sulfide, is toxic to humans and highly corrosive to steel pipe. On the morning of March 25, 1970, as the rig crew pulled out of the hole with a Smackover core, the well started gaining mud from gas pressure below. When they had pulled the core up to 10,000 feet, the pressure at the well head was 6,000 pounds per square inch. The blowout preventers activated and shut the well in.

High-pressured gas ruptured the well's casing, invaded the shallow aquifers, and blew the pump out for the water well that supplied water for the drilling activities. A worker was overcome by gas fumes at the well site, even though he was wearing a gas mask; attempts to revive him off site were unsuccessful. An autopsy indicated that toxic gas entered the man's body through a perforated eardrum.

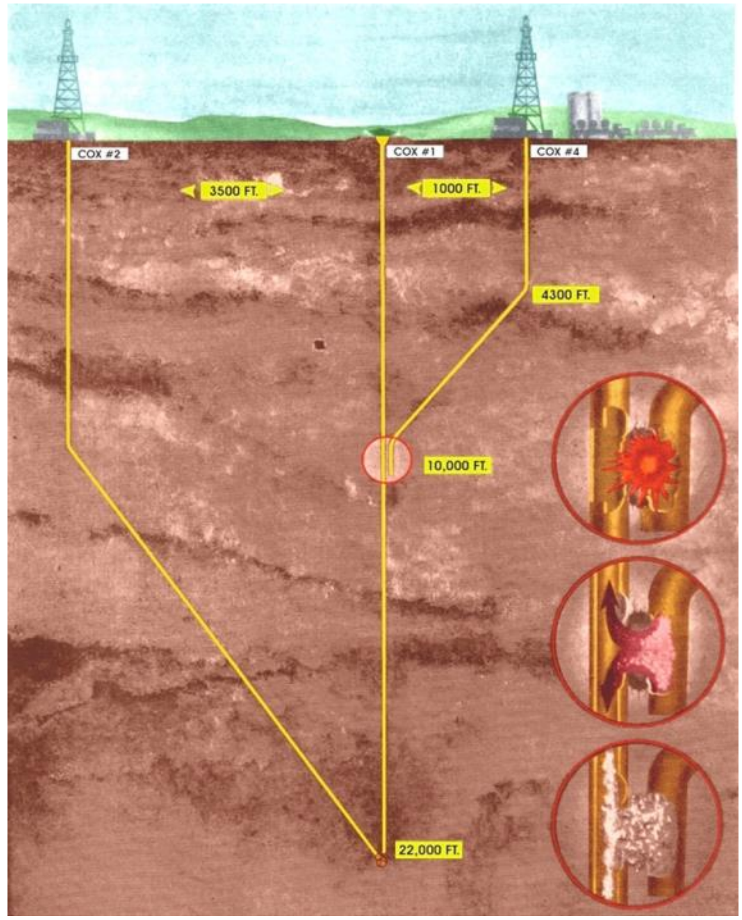


Figure 383. Shell Oil Company's plans to permanently seal off the Cox No. 1 gas well as announced on November 24, 1970. The Cox No. 2 relief well (at left) was a conventional intercept well, but its success was deemed problematic due to the depth required. The Cox No. 4 (at right) represented a new concept to intercept the annulus of the blowout well, perforate the casing, and fill the blowout annulus with cement for a permanent kill (see inserts at right). Image 2114.

Within thirty minutes, the crew had abandoned the well site. The blowout preventer stack rose and fell over, releasing a stream of gas and oil-emulsion mud. Within minutes the mixture exploded, blowing over the derrick and creating a crater at the well site. Surface control of the blowout was impossible. The Highway Patrol and Civil Defense were notified, and an area within a three-mile radius of the well was evacuated. Police evacuated 350 students from nearby Piney Woods School. The famous oil well firefighter Red Adair was called and asked to fly to Jackson.

When Shell's New Orleans On-shore Division Manager, Charlie Blackburn, flew to Jackson with a team of company specialists, he first circled the burning well. According to Alan Cockrell's (2005) account in his book *Drilling Ahead, The Quest for Oil in the Deep South 1945-2005*, Blackburn described the well site in the quotes: "It looked like a volcano," and "It looked like a crater." After Blackburn landed at Jackson, he was appalled to see National Guard troops and the Governor of Mississippi waiting for him. The Governor asked what was happening and if Red Adair was coming; he seemed satisfied when Blackburn said that Adair was on his way. The well fire was easily visible from downtown Jackson some 25 miles away and could be monitored by geologists from their office windows in the Petroleum Building. Within a week of the disaster, shifting winds carried the rotten egg smell of hydrogen sulfide to Jackson. Safety assurances from Charlie Blackburn narrowly averted a frantic evacuation of the Capital City.

Geopressured Basins of the United States (after Wallace, 1982)

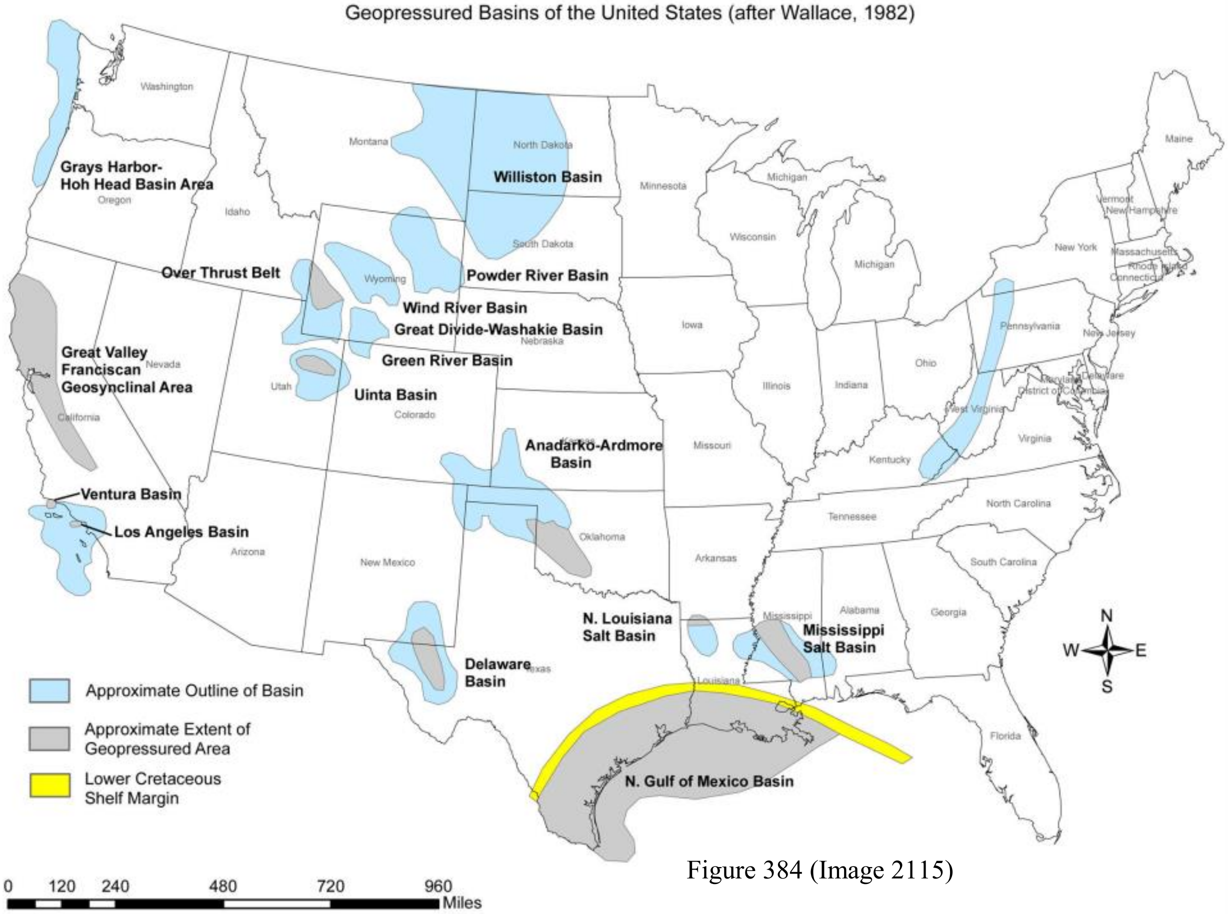


Figure 384 (Image 2115)

Monitor wells were drilled to bleed gas from the local aquifers, and Shell bought the forty-acre tract around the burned-out well. The well eventually bridged itself, and the flow of gas stopped. However, it would be a full year before another drilling rig intercepted the well and sealed it with cement.

The volume of gas that invaded local aquifers from the # 1 Cox blow out was impressive. The Shell #2 Shell-Cockfield monitor well in Section 28, T. 3 N., R. 3 E., Rankin County, was completed May 26, 1970, and produced one million cubic feet of gas per day from a two-foot interval at 1,317-1,319 feet with a tubing pressure of 350 pounds per square inch on a 27/64ths-inch choke. The Shell #5 Shell-Sparta in the same section was completed on July 4, 1973, and produced 583,000 cubic feet of gas per day at 1,495 feet with a tubing pressure of 285 pounds on a 25/64ths-inch choke.

Several other monitor wells also produced respectable volumes of gas from shallow aquifers. There were probably many anxious moments for the monitor-well drillers. John Marble recalled arriving to log one monitor well as the drill crew was fleeing the rig expecting it to blow. They had panicked at the smell of H_2S bubbling from their drilling mud. Fortunately, most of the gas produced from the shallow aquifers was in the form of methane.

The challenge to kill the #1 Cox led to the first direct intersection of a blowout well using a detection method. Specifically, wireline instruments were used for the first time to detect the location of a well bore by measuring distance and direction from the relief well to the blowout casing, and to home in on the magnetism of the blowout casing. Shell's plan consisted of: (1) drilling an intercept well to about 10,000 feet in such a way that the intercept well casing and the blowout well casing were in contact, (2) cementing the two strings together, (3) perforating the strings to create communication, and (4) pumping cement into the blowout well to kill it (**Figure 383**). The plan worked, and the well annulus was intersected and perforated at 10,500 feet and sealed with cement. According to Wright and Flak (website), "This success was the beginning of the modern relief well, establishing strategy and planning for future relief well projects and the basis for commercial casing detection instruments."

Figure 384 shows the distribution of geopressured areas in the United States. The first encounter with high-pressure gas in the Smackover of Mississippi was George Vasen #1 Tung Corporation of America drilled on the Wiggins Anticline two miles northeast of Wiggins in Stone County. This well was completed in 1952 at a depth of 20,450 feet and was the second deepest well at that time. According to Alan Cockrell (2005), the well "kicked hard" and blew 100 barrels of drilling mud into the derrick while coring at 20,300 feet and lost another 200 barrels of mud at 20,352 feet. The smell of hydrogen sulfide made the drill crew uneasy. Jay Ishee (personal communication), publisher and editor of Southeastern Oil Review, remember going to the well and finding it abandoned by the crew due to the smell of sour gas. Upon completion on September 7, 1952, the well flowed sour gas for several hours and then died, possibly due to a faulty cement seal in the liner.

The Shell #1 Cox blowout occurred in a deltaic sand facies within the Smackover peculiar to west-central Mississippi and adjoining portions of Arkansas and Louisiana (**Figure 370**). This sand facies has been equated with an ancient course of the Mississippi River. According to Steve Walkinshaw (Vision Exploration website), this ancient delta consists of a series of delta fans of varying geometries and thicknesses and comprises the prolific but highly over-pressured Deep Smackover Gas Trend. This trend has produced over 750 billion cubic feet of gas with a single well producing 192 billion cubic feet of gas.

The discovery well for Johns Field, the Caley T. Jones 33-10 #1, in southeastern Rankin County was spudded on January 11, 1980, and completed October 17, 1980. Later this well blew out during a work over, driving the owner into bankruptcy. After the blowout, a quickly-called meeting was held at a local school. Jim Hoffmann (personal communication) told an account given to him of that meeting by the late Fred Hille, who was then an employee of the Office of Pollution Control. There was a large crowd with cameras and members of the press asking questions of state and local officials concerning the danger to the public and how long would it take to get the well under control.

Under the title "Balls of Fire," Cockrell (2005) gave the account of the state's third blowout well, the Bean Resources No. 1 Beard 29-7 in the Smackover Formation on a salt ridge in Wayne County. On a routine day in April of 2001, Ken Magee of Spooner Petroleum Company visited the Beard well and found

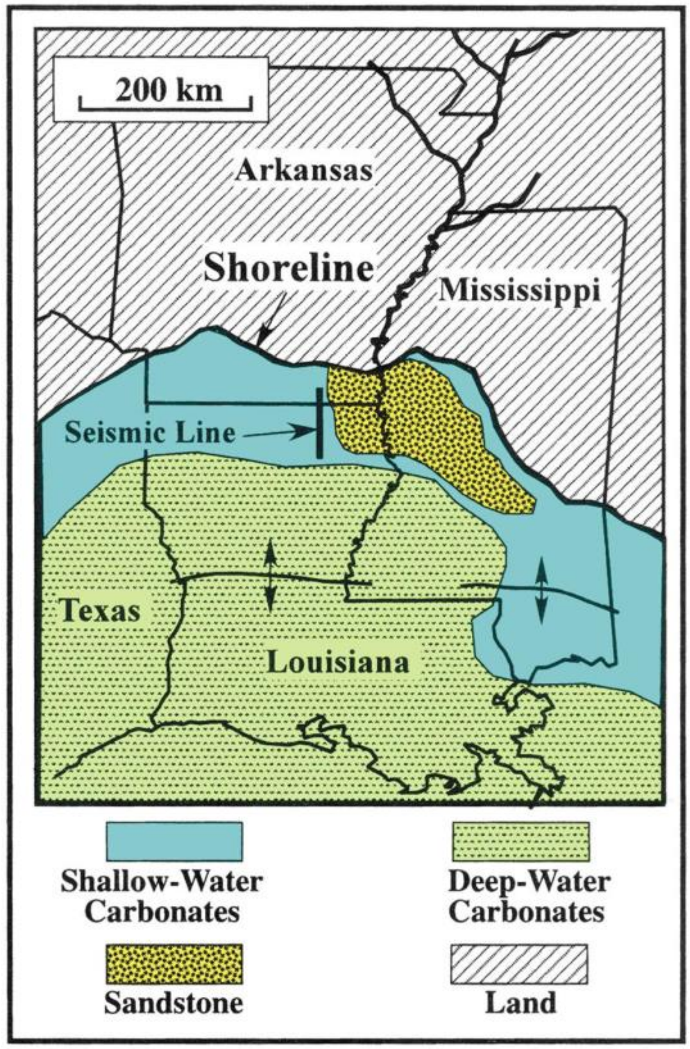


Figure 385. Distribution of sandstone and accompanying over pressured gas in the deep Smackover trend of southwestern Mississippi (from Heydari and Baria, 2005, p. 322). Image 2116.

the crew scurrying around the drill floor where drill mud was spewing across the shale shaker at an abnormally high rate. He ordered the well shut in. When Magee went to the trailer to call the company, he heard a loud noise and looked up to see joints of casing spewing up the derrick. The tool pusher closed the blind rams as the crew fled the rig. The rams held, catching three joints of casing sticking 90 feet in the air. After the manifold pressure stabilized at 2600 pounds per square inch, the blind rams were opened again, hoping the casing would slide back down the hole. The casing did move down on the first attempt, but, on the third attempt, the casing came flying up, creating balls of fire as it crashed against the derrick.

Figure 386. The Bean Resources #1 Beard 29-7 well blowout in Wayne County. Pictures (digital; Images 2117-2120) from Mike Spooner.

After several joints of casing were blown from the hole, the well began blowing mud and gas with a thunderous noise. Magee made his was to the accumulator near the rig, as the crew yelled for his to get away, and started closing the valves. The flow stopped when he closed the blind rams. After a moment of silence, the flow resumed with a roaring gas geyser of possible deadly sour gas. Flares were fired at the gas plume, which ignited, and, within fifteen minutes, the rig melted and collapsed (**Figure 386**). The blowout well was diverted in ten days and killed in twenty-one days. A new discovery well was drilled on the site, and the field was called the Ocean Forest Field. Cockrell (2005) summed up the blowout stating that Ocean Forest Field was a name that Ken Magee "won't likely forget," and that the drill crew would not likely forget Ken Magee.

Salt Water Disposal

Salt water disposal is a problem for the petroleum industry, especially for aging oil fields. As oil is withdrawn from a field, the salt water beneath the oil pool is drawn upward to the producing wells, resulting in an ever increasing quantity of salt water production (from almost no salt water up to 20 barrels of salt water for one barrel of oil). In the early years of oil production, much of the salt water was allowed to discharge onto the surface or in creeks, killing trees and aquatic wildlife. This practice was discouraged, and then prohibited, by the Mississippi Oil and Gas Board and was replaced in many fields by earthen evaporation pits. These evaporation pits, which statewide numbered in the thousands, had sandy porous levees and bottoms through which the salt water drained into nearby wetlands.

Figure 387. Producing well in North Yellow Creek Field in Wayne County, Mississippi, adjacent to a salt water line draining into a local creek. Picture (negative 203-6; Image 2121) was taken in October of 1978.

Figure 388. Salt water line from the North Yellow Creek Field leading to a local creek. Picture (negative 203-9; Image 2122) was taken in October of 1978.

Figure 389. Salt water line draining onto the ground next to a local creek in North Yellow Creek Field. Picture (negative 203-7: Image 2123) was taken in October of 1978.

The problem of freshwater contamination due to salt water disposal began with the state's first oil field at Tinsley in Yazoo County. When Kalkhoff (1986) published on the brine contamination in petroleum producing areas in Mississippi, he reported that field personnel were unable to locate shallow wells (approximately 100 feet deep or less) in the "Citronelle Formation" (now recognized as the pre-loess terrace deposit) in Tinsley Oil Field. Sands and gravels of the pre-loess terrace was the main domestic water supply source at Tinsley as the next aquifer lay beneath a thick section of Yazoo Clay. Numerous land owners said that they once had shallow wells that produced water of good quality, but subsequently (after oil production) these wells produced salty water and were destroyed. In his study, Kalkhoff defined water with chloride concentrations below 20 milligrams per liter (mg/L) as uncontaminated, at 20-50 mg/L as probably contaminated, and greater than 50 mg/L as contaminated. Though prohibited, surface disposal of oil field brines was done to some degree in North Yellow Creek field in Wayne County as late as 1978 (**figures 387-389**).

Baughman and McCarty (1974, p. 279-286) reported certain tributaries of the Chickasawhay River, including Eucutta Creek, Yellow Creek, and Hortons Mill Creek, were polluted with oil-field brines. They stated that "surface water in the areas of West Eucutta, Eucutta, North Yellow Creek, Yellow Creek, Chaparral, and Diamond oil fields had chlorine contents measured in excess of 250 milligrams per liter," which was the limit established by the U. S. Public Health Service for chlorides in drinking water. Salt water contamination in these fields was attributed to the use of unlined salt water evaporation pits. To show the source and effects of salt water seepage,

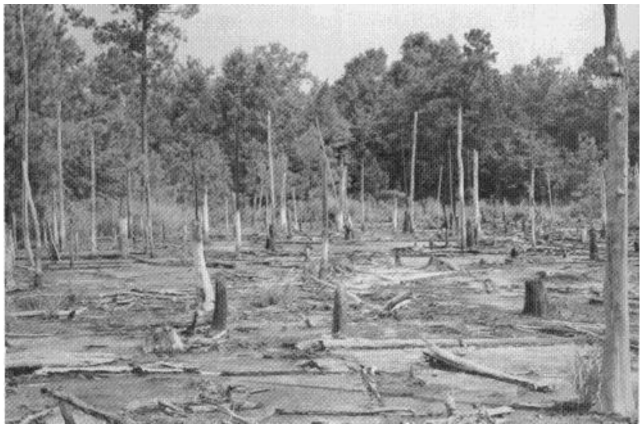


Figure 390. Dead trees and barren ground poisoned by salt water from a leaking salt water evaporation pit in Eucutta Oil Field in Wayne County. Picture (Image 2124) was taken in August of 1973 and is from Baughman and McCarty, 1974, p. 284, fig. 4.

Figure 391. Overflowing salt water evaporation pit in West Eucutta Oil Field in Wayne County. Little Eucutta Creek is on the other side of the tree kill. Picture (Image 2125) was taken in August of 1973 and is from Baughman and McCarty, 1974, p. 285, fig. 5.

Figure 392. Tanker truck dumping salt water from an Alabama oil field into an evaporation pit in Eucutta Oil Field in Wayne County. Picture (Image 2126) was taken in August of 1973 and is from Baughman and McCarty, 1974, p. 286, fig. 6.

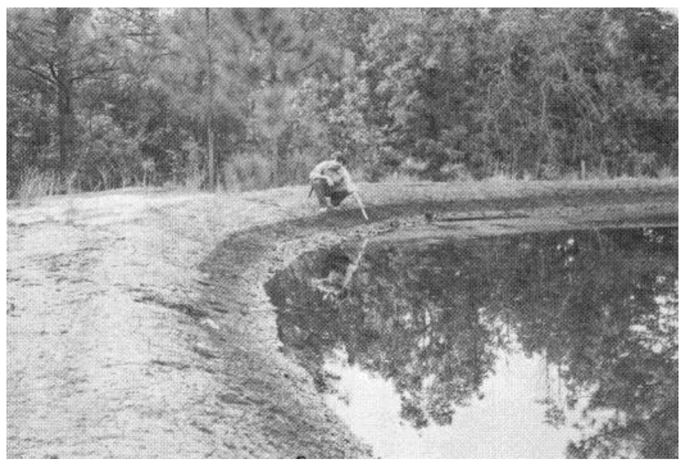


Figure 393. A salt water evaporation pit with a high seepage rate, and where the surface is completely covered in crude oil impeding evaporation, in Eucutta Oil Field in Wayne County. The knife edge is at the fluid level of the pit approximately three hours prior to this photograph. Picture (Image 2127) was taken in August of 1973 and is from Baughman and McCarty, 1974, p. 287, fig. 7.

Baughman and McCarty illustrated tree kills next to leaking salt water evaporation ponds (**Figure 390**), a salt water evaporation pond overflowing into Little Eucutta Creek (**Figure 391**), salt water from an Alabama oil field being dumped into an evaporation pit in Eucutta Oil Field (**Figure 392**), and a rapidly seeping evaporation pond in Eucutta Oil Field (**Figure 393**). The practice of trucking Alabama salt water for disposal in Wayne County evaporation ponds was a result of the enactment of stronger environmental regulations in Alabama.

Childress et al. (1976) illustrated a large salt water disposal pit in Adams County and a fertile field below it that had been destroyed by salt water leaking from the pit in the late summer of 1974. They noted that much of Adams County was underlain by loess, sand, and gravel and that these materials were quite permeable, allowing salt water in pits to mix with surface water and shallow aquifers. To address this problem in Adams County and statewide, the State Oil and Gas Board issued Statewide Rule 63 on October 17, 1973, which ordered the backfilling of evaporation pits and made provisions that new pits be permitted for only one year, be lined with an acceptable impervious material, and be inspected by the State Oil and Gas Board prior to use for salt water storage or evaporation.

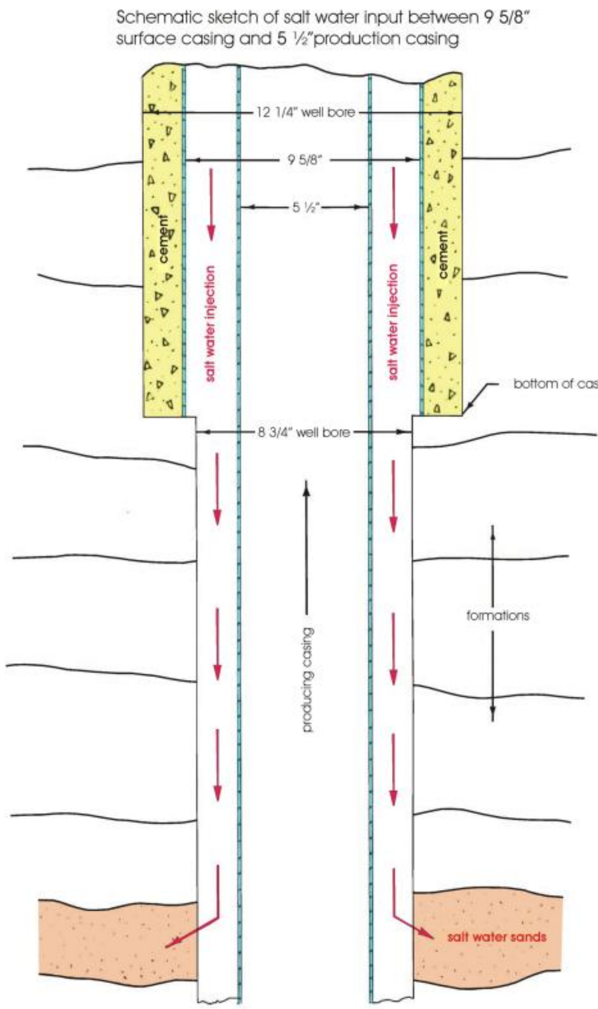


Figure 394. A schematic drawing of salt water injection down the annulus (between surface casing and production casing) of a producing oil or gas well. Figure modified from Bicker,1972, p. 12, fig. 2. Image 2128.

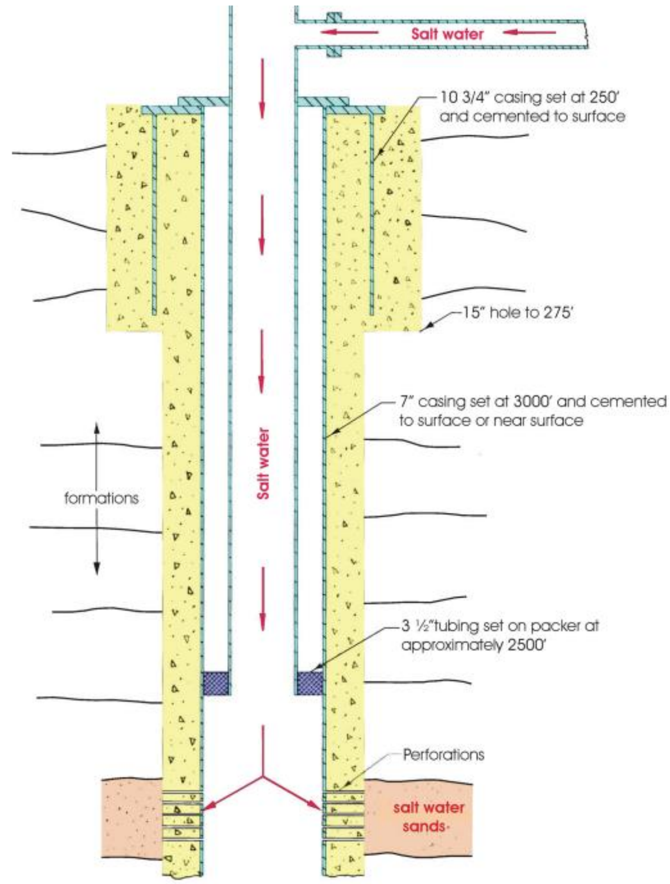


Figure 395. A schematic drawing of an example of a properly designed salt water disposal well. Figure modified from Bicker, 1972, p. 11, fig. 1. Image 2129.

Kalkhoff (1982) analyzed 224 ground-water and 190 surface water sites collected from six oil producing regions of Mississippi during low stream flow in 1980 and 1981. Samples from 17 ground-water and 55 surface-water sites had dissolved chloride concentrations in excess of 100 milligrams per liter. One surface water sample taken from a spring in Jasper County produced the maximum contamination found, 15,000 milligrams per liter.

Kalkhoff (1986) published on the brine contamination of the shallow ground water and streams in the Brookhaven Oil Field in Lincoln County, Mississippi. Since 1943, the disposal of some 54.2 million barrels of salt water in that field contaminated the Citronelle and Hattiesburg aquifers with brine produced from the Tuscaloosa Formation. The Citronelle aquifer within a five square mile area of the field was contaminated with chloride concentrations greater than 20 milligrams per liter. Spring water from the Citronelle aquifer contaminated Shaws Creek during low flow, which was 87 per cent of the time. A second study of the Brookhaven Oil Field by Slack et al. (1996), showed water from 89 of 177 wells (50%) to be contaminated with brine (over 20 milligrams of chlorine per liter), ranging from 2.5 to 9,400 milligrams per liter. However, only 12 wells (7%) exceeded the recommended secondary limit for drinking water (250mg/L).

Today, salt water disposal wells are the approved method for disposing of salt water. These wells inject salt water into subsurface aquifers that already contain salt water. For many years, some oil companies accomplished this by using their producing oil wells for salt water disposal by injecting the salt water down the annulus of the well between the surface casing and the production casing or tubing (**Figure 394**). This short cut system was discontinued in 1973 (Statewide Rule 63) because it allowed salt water to leak into freshwater aquifers through corrosion of the surface casing. **Figure 395** is a schematic drawing of an approved salt water disposal well design in which the salt water is injected through the production tubing directly into a salt water aquifer.

Bicker (1972) published a Mississippi Geological Survey Information Series entitled "Salt Water Disposal Wells in Mississippi," which recorded approximately 395 disposal wells located at oil and gas field in 25 counties as of December 1971. Injection wells for waterflood or secondary recovery operations were not included in the total of disposal wells. Perhaps the first salt water disposal well was drilled in Tinsley Oil Field in 1942, just three years after the field was discovered. In January of 1971, 386 producing oil and gas pools generated 16,406,813 barrels of salt water per month. This salt water was injected into aquifers ranging in age from the Cretaceous Tuscaloosa Formation to the Miocene Catahoula Formation. These, in ascending order, were the Tuscaloosa, Eutaw, Wilcox, Kosciusko (Sparta), Cook Mountain (*Camerina* limestone), Cockfield, and Catahoula. Bicker noted that the extreme depth of the Tuscaloosa and Eutaw formations added to the cost of disposal, making the shallower aquifers more attractive as a disposal medium.

Bicker (1972) also recognized the potential pollution of fresh water zones by the permitting of salt water disposal wells into aquifers with less than 1000 parts per million of total dissolved solids. This was the apparent case in the lower Wilcox aquifer in the Heidelberg East Field in Jasper County, where the aquifer was calculated from electric logs to have dissolved solid content well below 1000 parts per million and most certainly below the 10,000 parts per million cutoff level set forth in the rules and regulations of the Oil and Gas Board (Order No. 430-70 and Statewide Rule 63). At the Heidelberg East Field, the base of the fresh-water zone was picked at a depth of 2,930 feet, thus the temptation to use the Lower Wilcox aquifer rather than a much deeper one. Bicker recommended that chemical analyses be run on formation waters in proposed disposal zones before injection permits are granted.

The Heidelberg Oil Field was discovered in 1944 with initial production in the Eutaw Formation. Addition discoveries included deeper formations, resulting in more that 200 producing well in the field. Hille et al. (1986) reported that since 1950 some 410,000,000 barrels of oil field brine, ranging from 47,000 to 168,000 milligrams of dissolved solids per liter, had been injected into the sands of the lower Wilcox aquifer in the vicinity of Heidelberg. They also noted that water-supply wells in that same aquifer included: (1) the Rose Hill Water Association with one 1,890-foot-deep well about 17 miles north of Heidelberg, (2) at least 12 wells in Clarke County, with those for the City of Quitman as much as 1,934 feet deep, (3) the Town of Shubuta had a 2,286-foot-deep well about 16 miles east of Heidelberg, (4) the Hiwannee Water Association had a 2,368-foot-deep water well in Clarke County and a 2,777-foot-deep water well in Wayne County, and (5) the town of Waynesboro had a 2,402-foot-deep well. The lower Wilcox aquifer was characterized as the deepest and most extensive aquifer system in the area of Jasper, Clarke, and Wayne counties, where wells screened in the aquifer yielded more than 1,000 gallons per minute.

At Heidelberg, the lower Wilcox aquifer is from 300 to 350 feet thick and occurs at depths of 2,300 to 2,600 feet. Even though the resistivity curve of electric logs in this interval indicated that it contained fresh water, those who used the Lower Wilcox for salt water disposal claimed the contrary. In January of 1985, the Mississippi Department of Natural Resources drilled a well in the town of Heidelberg to test the water quality of the lower Wilcox aquifer. Geophysical logs run on the well gave a resistivity reading of 27 ohm-meters (at the sand interval to be screened) at a formation water temperature of 101 degrees Fahrenheit. Based on a calculation devised by Newcome (1975), these values indicated a dissolved solid content of 667 milligrams per liter. When the formation water was pumped and sampled, it yielded a specific conductance of 900 micromhos and a value of 596 milligrams per liter of total dissolved solids. This test demonstrated that electric logs could be used in the lower Wilcox aquifer at Heidelberg to estimate the value of total dissolved solids and that oil field brines were being injected into a potentially valuable aquifer. Salt water injection into the lower Wilcox aquifer at Heidelberg was discontinued. The geophysical log for the McGowan #1 L. H. Eddy well in the Heidelberg Oil Field shows the boundary between salt water injected into the lower Wilcox aquifer and the relatively freshwater (about 1,000 milligrams of total dissolved solids per liter) above (**Figure 382**). The boundary is seen in the abrupt shift from low to high resistivity in the resistivity curve at 2,815 feet below the surface. In this well, fresh water could be pumped from the upper part of the aquifer, but, if the pumping rate were too high or the screen was set too near the fresh water-salt water interface, the well could draw in salt water from below in a phenomenon called upconing.

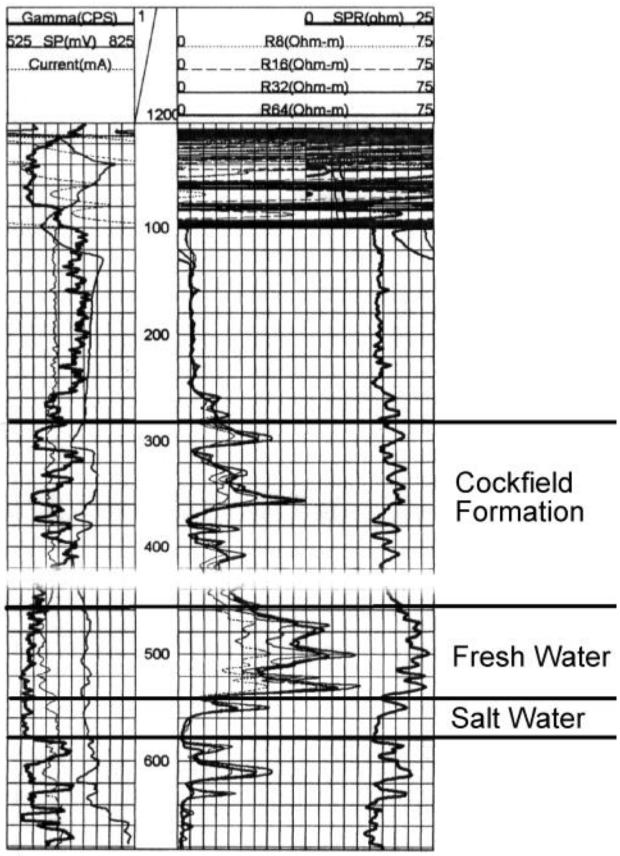


Figure 396. Denbury Resources #3 Lank Smith Borehole ID 163R0082, in Tinsley Oil Field in Yazoo County, Mississippi. Tinsley is the oldest oil field in the state and has salt water in its shallow aquifers due to unregulated practices in its early development. The salt water lens shown here is in the base of the Cockfield aquifer.

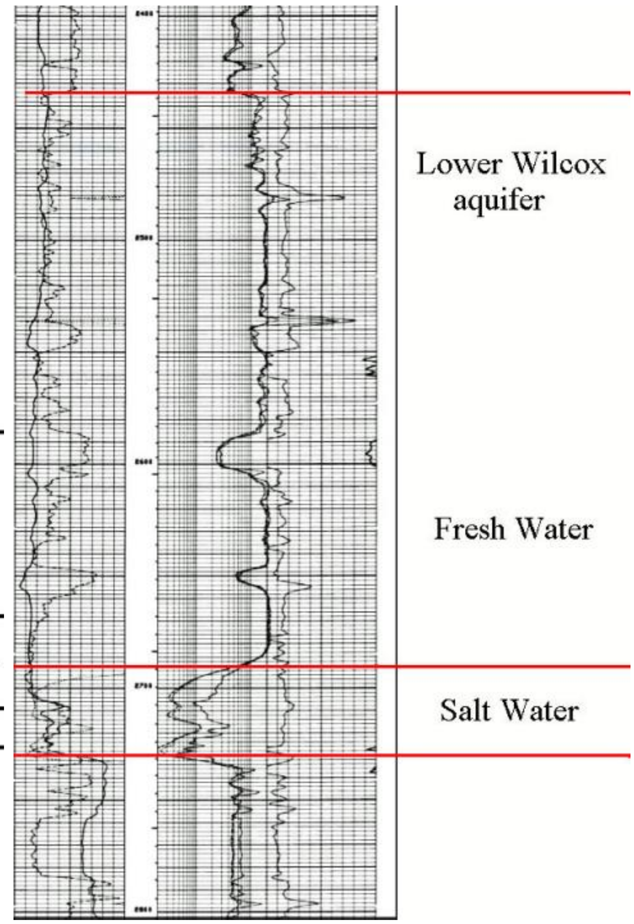


Figure 397. Geophysical log of McGowan L. H. Eddy Estate #1 well in East Heidelburg Field, Jasper County, Mississippi, showing the Lower Wilcox aquifer with a zone of injected salt water below the fresh water interval. The log interval above is from 2,300 to 2,700 feet below ground level.

Figure 397 Caption Continued. The geophysical log in **Figure 397** is the 5-inch version of the 1-inch log published by Hille, Hoffmann, and Erustun (1986) in their Figure 5. In the subsurface, sands of the Oak Hill and Coal Bluff members of the Naheola Formation are included in the Wilcox Group as the Lower Wilcox aquifer. Hille et al. (1986) placed the apparent interface between fresh and salt water in the McGowan—Eddy Estate #1 at 2,690 feet below ground level as is shown above. Fresh water above the interface was estimated to have an average value of total dissolved solids of approximately 1,000 milligrams per liter.

Hille et al. (1986) concluded from the results of their calculations that: "There are substantial supplies of fresh water in the lower Wilcox aquifer in Heidelberg oil field which might be developed, particularly in those areas of suitable water quality located some distance from injection wells which disposed of salt water in the aquifer. In selecting sites for the location of water wells, it would be advisable to utilize electric logs from wells and test holes in the immediate area to determine the available water quality and the thickness of the aquifer section suitable for sreening a well above the salt water interface. It is obvious from the calculations that at a location where there is not water of desirable quality, it might not be possible to produce enough water to justify a well. On the other hand, these results also indicate that a location where the aquifer contains a supply of good quality water which is sufficiently separated from an interface, it may be possible to produce more than 1,000 gal/min from the lower Wilcox."

Naturally Occurring Radioactive Materials (NORM) in Produced Formation Fluids

Naturally occurring radioactive materials (NORM) in oil field produced formation fluids (brines) are enhanced during oil and gas production, resulting in radioactive scale on production tubing. Ericksen (1995) published a data set of over 2,800 laboratory determinations of the mineral constituents and/or resistivity of formation samples from wildcat wells and 241 oil, gas-condensate, and gas fields in Mississippi. This study included all major petroleum productive formations in the state, with production depths ranging from the Carter Sandstone at 653 to 687 feet in Itawamba County to the Cotton Valley at 20,000 feet in Copiah County. Total dissolved solids analyzed in the samples ranged from 8,500 milligrams per liter in the Paleozoic in Clay County to 380,767 milligrams per liter in the Jurassic Cotton Valley Formation in Jasper County.

Of particular interest in Ericksen's study were the five elements calcium, barium, strontium, radium, and lead, which precipitate on production tubing and equipment as scale. Radon occurs in some petroleum, and residues from the oil and natural gas industry often contain radium and its daughter products. Sulfate scale from an oil well can be radium rich, while radium's daughter product radon is often found in water, oil, and gas. Radon decays into solid radioisotopes, which contribute to the radioactive components of sulfate coatings inside oilfield pipework.

At times when scale buildup restricts production, the production tubing is pulled and replaced at the well site. The radium in oil field scale is a decay product of thorium and uranium, which occur naturally throughout the earth's crust. It is also an alkali earth metal belonging to group IIA in the periodic table along with calcium, barium, and strontium, which occur with it in oilfield scale. The occurrence of radioactive radium in scale deposited on production tubing, heater treaters, salt water tanks, and separators possess a possible health hazard as does the disposal of scale from this equipment at production sites. Chemical analyzes in Ericksen's report did not include analyzes for radium and lead, but did include the values of calcium and undifferentiated barium and strontium (with are associated which radium). The value for undifferentiated barium and strontium ranged from 0 in several field to 3,700 milligrams per litter in Diamond Field in Wayne County.

NORM study procedures for on-site sampling of oil-field brines were devised to help minimize the amount of oil included in the samples. The preferred source of samples was straight from the well head (**Figure 398**), but this was not always possible because of oil/water emulsion that would not separate or for lack of a valve at the well head. Other sample sources, in order of preference, were (1) flow lines from the well head, (2) separators, (3) heater treaters, and (4) salt water storage tanks. The sample from the well head was first collected in a 5 gallon bucket with a valve at its base. After filling, the container was allowed to sit before the water was drained from the valve into a 4 liter sample container (**Figure 399**).

Figure 398. Collecting a brine sample at the well head.. Picture (Image 2130) from Ericksen et al., 1999, p. 14, fig. 2.

Figure 399. Transfer of brine sample into sample collection bottle. Picture (Image 2131) from Ericksen et al., 1999, p. 14, fig. 3.

CHAPTER 10. GEOLOGY AND PUBLIC HEALTH

RADON IN MISSISSIPPI

The following is, in part, from the February 2012 of *Environmental News*, (Dockery and Thompson, 2012, p. 14-18: Radon in Mississippi).

Radon is an odorless and colorless, naturally-occurring, radioactive gas derived from the decay of radioisotopes of uranium and thorium and is the heaviest of all the noble gases of the Periodic Table. All isotopes of radon are highly radioactive. If condensed to a liquid (at very low temperatures), radon glows in the dark due to its intense radiation. The most stable isotope of radon, ^{222}Rn, has a half-life of only 3.8 days, thus radon levels diminish with time and distance from its source. Granite and shale generally contain the highest quantities of uranium and thorium and tend to produce the highest quantities of radon gas. Other rock types that are likely to produce radon are glauconite-bearing sandstones, certain kinds of fluvial sandstones and sediments, phosphorites, chalk, karst-producing carbonate rocks, certain kinds of glacial deposits, bauxite, and silica-rich volcanic rocks. Most of the radon produced in these rocks is trapped in the deep rock interior and ultimately decays in a number of steps to form the stable isotope of lead ^{206}Pb. However, radon produced near the exterior, or along fractures of these rocks, may work its way to the surface. Mississippi has many near-surface deposits of shale and clay, but the state's granite sources are deeply buried.

Radon levels in the atmosphere (in the U.S.) are measured in picocuries per liter (pCi/L). The average random concentration of radon in American homes is about 1.3 pCi/L,

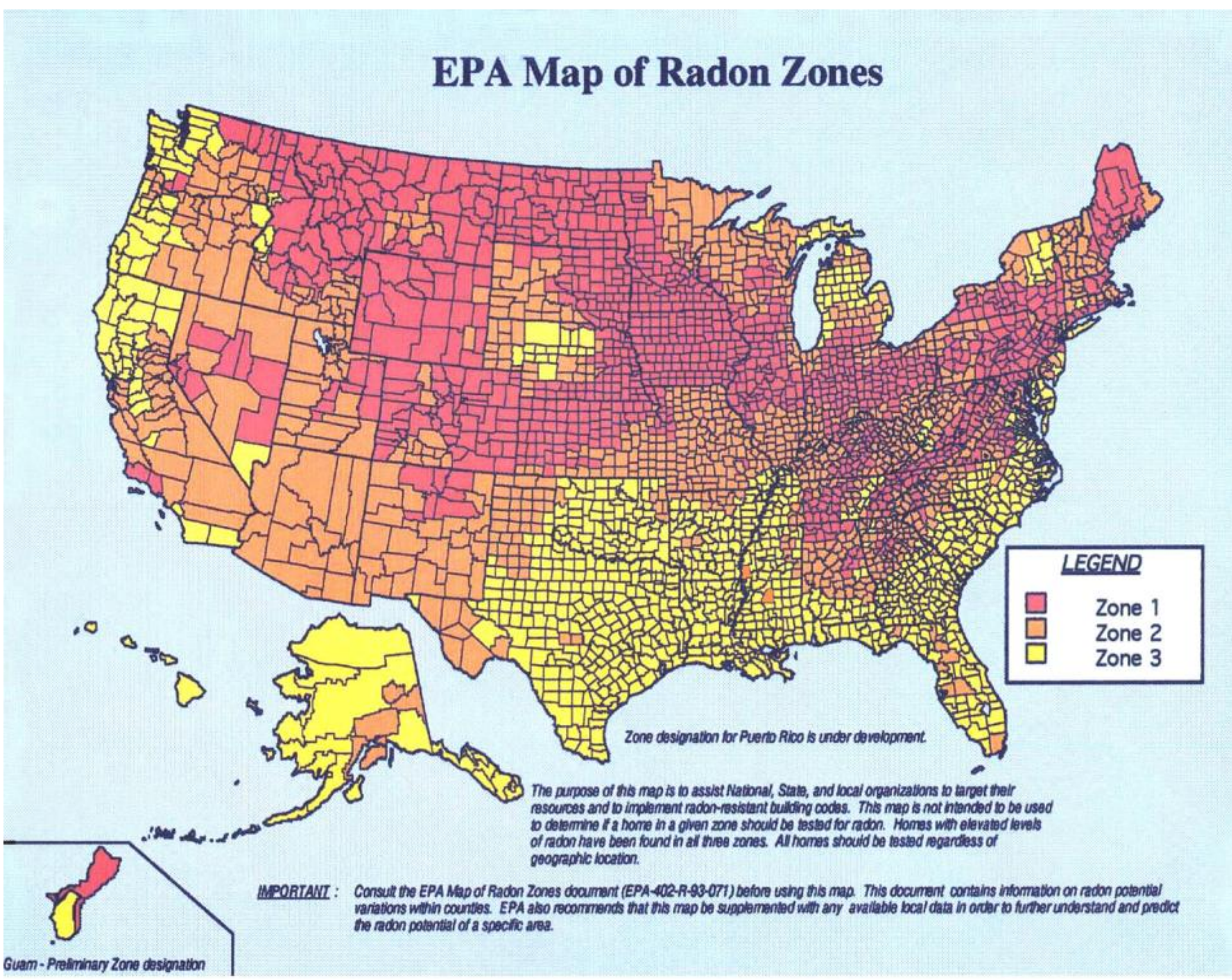


Figure 400. EPA radon zones for counties in the United States. The highest radon levels are in Zone 1 (red) and the lowest levels are in Zone 3. Image 2134.

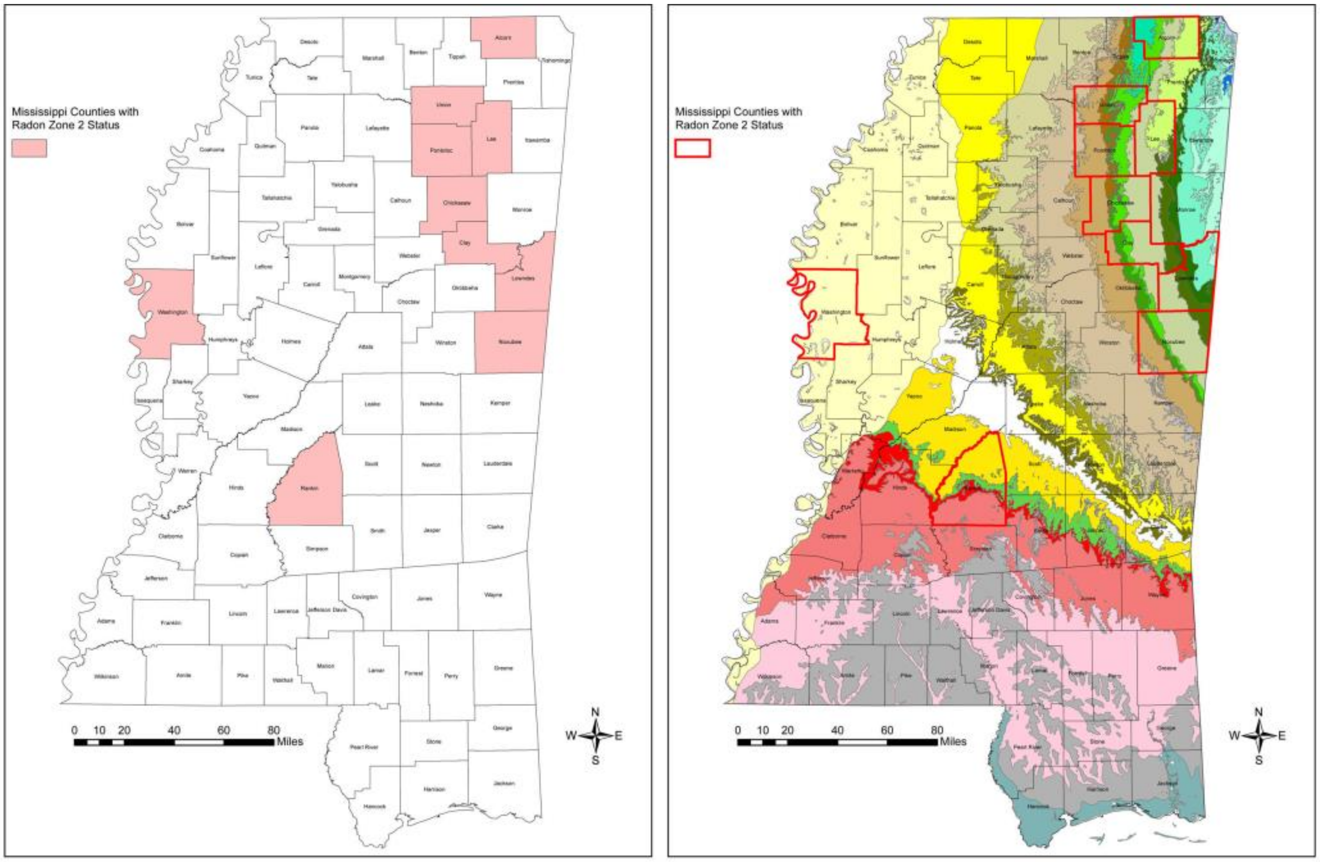


Figure 401. Radon Zone 2 counties in Mississippi (left) and their bedrock geology as shown on the state geologic map (right). Image 2135.

while outdoor exposures are about one tenth as much. The U.S. Environmental Protection Agency has divided the United States, by counties, into Radon Zones 1-3, with Zone 1 having the highest radon potential with levels greater than 4 pCi/L, Zone 2 having moderate radon potential with levels between 2 and 4 pCi/L, and Zone 3 having low radon potential with levels less than 2 pCi/L (**Figure 400**). Of the eighty-two counties in Mississippi, seventy-two are in Zone 3, and ten are in Zone 2 (**Figure 401**). Eight of the ten counties in Zone 2 occur along the Cretaceous outcrop belt and include, from south to north, Noxubee, Lowndes, Clay, Chickasaw, Pontotoc, Lee, Union, and Alcorn counties. The remaining counties are in Zone 2 and include Rankin County on the mid-Tertiary outcrop belt and Washington County on the Mississippi River Alluvial Plain. A county's placement in Zone 3 does not exclude homes in that county from problems with radon exposure. The NURE aeroradiometric thorium data map for the conterminous United States (**Figure 402**) and for the Mississippi area (**Figure 403**) indicate high levels of thorium in the Delta, the Loess Hills, and the Jackson Prairie, regions which include many of the state's Zone 3 counties.

Elevated radon concentrations associated with the Cretaceous belt in Mississippi, Tennessee, Alabama, and Georgia (as shown in **Figure 402**) may be due to both the shale and chalk components of the Selma Chalk Group, which underlies the Black Prairie Physiographic Province. Additional sources may come from heavy mineral occurrences that include the uranium and thorium-bearing minerals monazite and zircon in sand-rich geologic units of the Upper Cretaceous section.

Higher levels of radon in Rankin County might be associated with the uplifted basement rocks and buried volcano of the Jackson Dome under the western part of the county (**Figure 404**) or from such near-surface formations as the mineral-rich Bucatunna Clay and the Yazoo Clay. According to the Agency of Toxic Substances and Disease Registry *ToxFAQs*, the average soil content of radioactive thorium is 6 parts per million (6 ppm). Laboratory tests on the Bucatunna Clay at the

Figure 402. Leroy Strite (left) and Larry Strite (right) at the Easom Mine in the Bucatunna Clay in Smith County, Mississippi. Spring water draining off the top of the clay at left is blood red with minerals and/or sulfur-reducing bacteria. Picture (digital; Image 1723) was taken by Michael LaBelle on December 10, 2007.

Figure 403. Outcrop of Bucatunna Clay on the north side of Highway 18 across from Brandon High School. Picture (digital; Image 2139) was taken on July 27, 2011.

Easom Mine in Smith County (**Figure 402**) found thorium levels of 20.690 ppm, about 3.5 times the average level. **Figure 403** shows an outcrop of the Bucatunna Clay on Highway 18 in Brandon.

In April of 2000, the Office of Geology was contacted concerning the reason for high levels of radon found in a Washington County school (2.3% of the schools initially tested in Mississippi had radon concentrations of 4 pCi/L or above). The office was asked if the source of the radon might be from a buried volcano in that county. Washington County straddles a hinge line or possibly a fault along the north margin of the Monroe-Sharkey Platform where it plunges into the Desha Basin (**Figure 404**). Pat Mason (Office of Land and Water Resources, Hydrologic Investigations Report 2001-1) documented saltwater intrusion into the freshwater zone of the Cockfield aquifer above this hinge line just south of Greenville. She noted that the Cockfield in this area had anomalously high gradients in heads, color, chlorides, and pH, which suggested "the presence of faulting." Faulting could also be an avenue for increased radon levels. Anomalous increases in radon concentrations have been noted to precede earthquakes.

To test basement rocks as a source of elevated radon levels, a core of a volcanic rock with the composition of phonolite from a depth of 4,024 feet in the Mississippi Valley Gas #1 Terry Bell well in Washington County (**Figure 408**) was checked for radioactivity at the Radiological Health division of the Mississippi Department of Health. Phonolite is the same volcanic rock type that buried Pompeii and Herculaneum under as much as 80 feet of molten ash when Vesuvius erupted in 79 A.D. Michael E. Gates of Radiological Health (on April 12, 2000) found the core to be "colder than a brick" (bricks emit radiation from a radioactive isotope of potassium they contain). Other buried volcanic rocks in the county may be more radioactive, but their depth at 4,000 feet would lessen their impact as a source of radium, unless the radon could hitch a ride up a fault on a plume of saltwater. Another possible source would be the granite gravel and cobbles in the lower part of the alluvium in the Mississippi River Alluvial

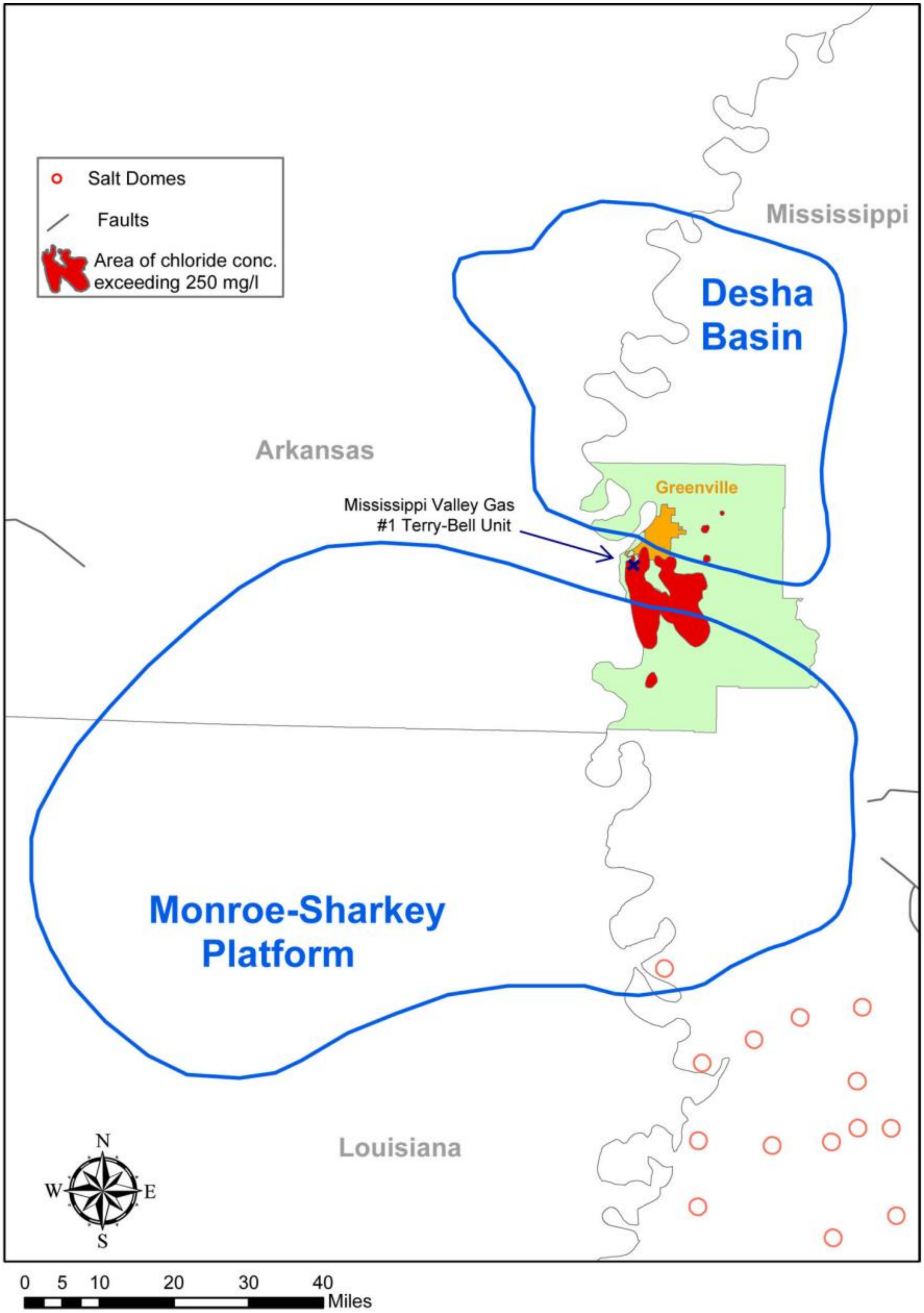


Figure 404. Location of Washington County, the Terry Bell well, and elevated chloride levels in the Cockfield aquifer in relation to the Monroe-Sharkey Platform and Desha Basin. Image 2140.

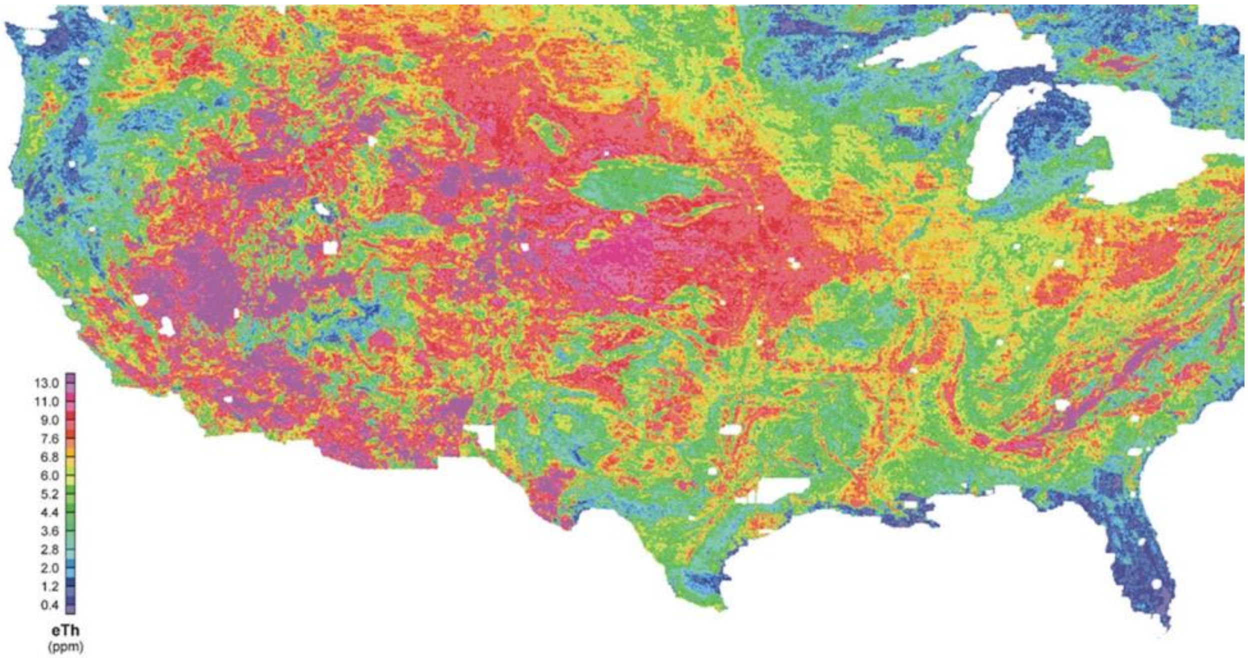


Figure 405. Aeroradiometric thorium data for the conterminous United States from the National Uranium Resource Evaluation (NURE) program of the U. S. Department of Energy. Data were collected by aircraft flying 400 feet above the ground surface and can provide an estimate of radon source strength over a region. Image 2136.

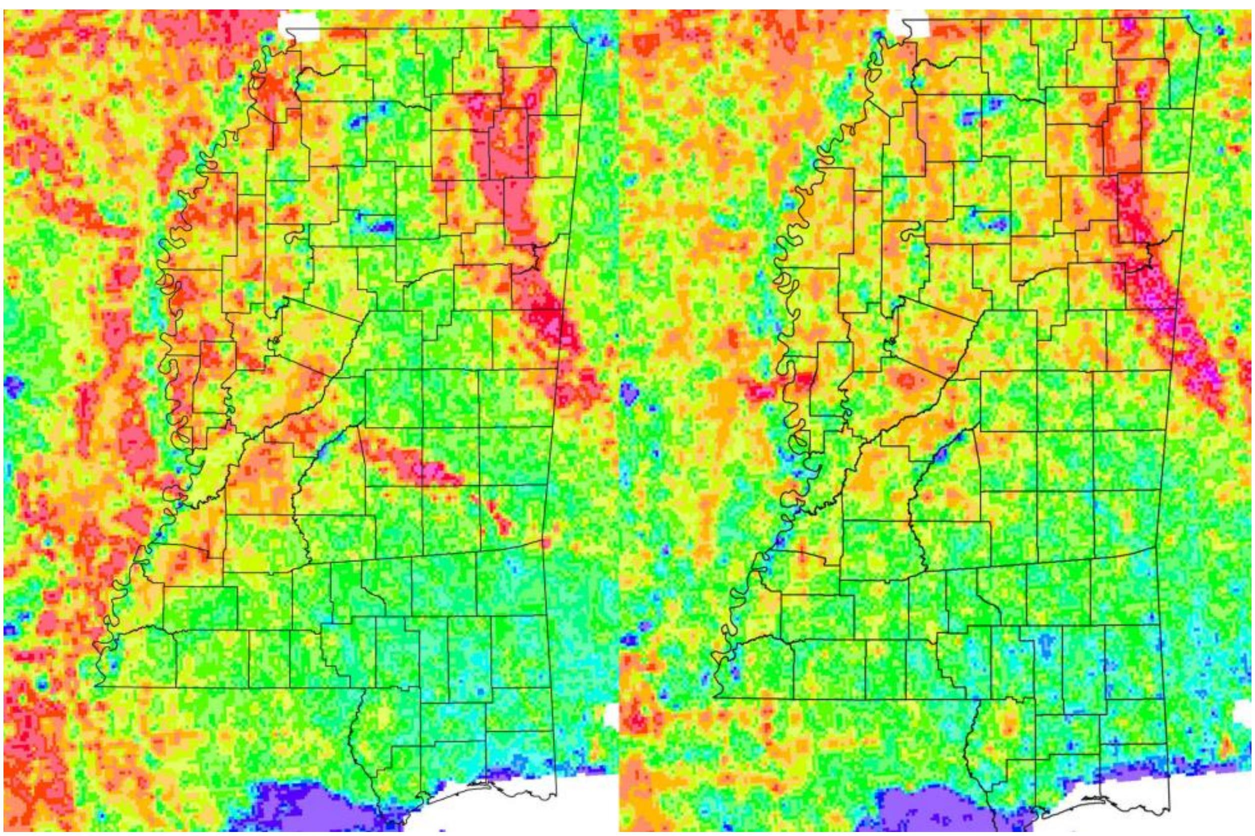


Figure 406. Enlargement of aeroradiometric thorium (left) and uranium (right) data maps for the Mississippi area. Red (on both maps) indicates high thorium and uranium concentrations in the Cretaceous outcrop belt of northeast Mississippi. High thorium concentrations (map at left) also occur in the alluvium of the Mississippi River Alluvial Plain, in the loess of the Loess Hills, and the Yazoo Clay of the Jackson Prairie. Image 2137.

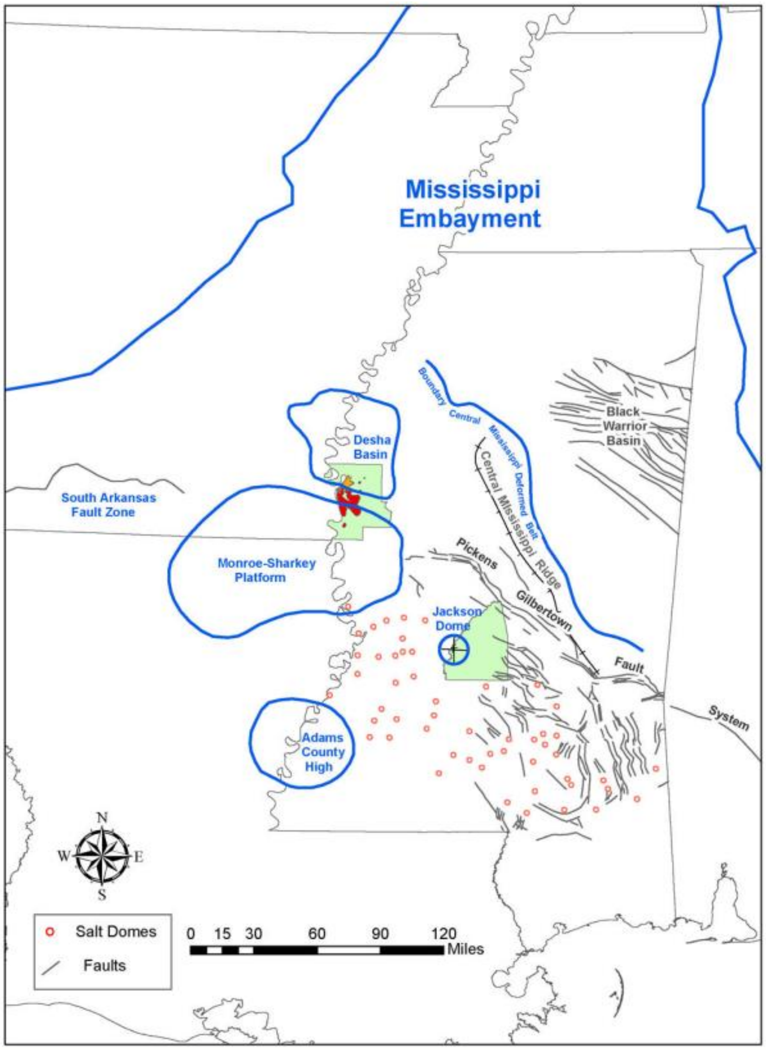


Figure 407. Structural map of the Mississippi Embayment, showing the location of Rankin and Washington counties. Image 2138.

Plain, which occur within a hundred feet of the surface. One in ten pebbles of Mississippi River gravel is composed of granite (**Figure 409**). Similar glacially-derived materials, ground from granitic rocks of the Canadian Shield, underlie the farm lands of Iowa, where all the state's counties are zoned in Level 1 (see **Figure 395**). Radon levels are so high in that state that cities such as Iowa City have passed requirements for radon-resistant construction in new homes.

Radon is a particularly dangerous source of radiation because it is taken into our lungs when we breathe. It is the second most frequent cause of lung cancer (after smoking) and is estimated to cause 21,000 lung cancer deaths per year in the United States (**figures 410-411**), some 2,900 of which occur among those who have never smoked. The Iowa Radon Lung Cancer Study (Field et al., 2000) found that a 15-year exposure (at home) at levels equivalent to EPA's action level of 4 pCi/L yielded a 50% increase in lung cancer risk. Radon exposure is especially damaging to smokers, due to the synergistic effects of radon and smoking, increasing their risk of cancer ten-fold over non-smokers. According to EPA estimates, at a radon level of 4 pCi/L over a lifetime for 1,000 smokers, 62 people could get lung cancer. Under the heading "What To Do," EPA says, "Stop smoking and fix your home."

Lung cancer caused by radon was first noticed as a wasting disease in miners in Europe as early as 1530. This condition was identified as lung cancer from an investigation of miners in Schneeberg, Germany, in 1879. In the United States, decades of health problems found in uranium miners in the Southwest (employed during the early Cold War) prompted the first federal establishment of limits on radon in mines in 1967. The most effective method found to control excess radon was the use of extensive ventilation systems with multiple vertical shafts and fans to supply fresh air.

Radon presence in indoor air was documented as early of 1950. Indoor radon became nationally publicized in 1984 when construction engineer Stanley Watras entered the Limerick nuclear power plant in Pottstown, Pennsylvania, on his way to work and set off the plant's radiation monitor alarms. As the plant was under construction, it had no nuclear fuel at the time. Further tests revealed that the radioactive substances on Watras were not from the plant, but were from the byproducts of high radon levels in his home. The daughter products of radon are radioactive solids that stick to dust particles in the air, which in turn can contaminate skin and clothing. Radiation measurements in the Watras home were 700 times higher than the maximum level considered safe for human exposure (the home tested at 2,700 pCi/L, far above the safe level at, or below, 4 pCi/L). Following this incident, Congress passed the Indoor Radon Abatement Act (IRAA), which directed EPA (in Sections 307 and 309) to

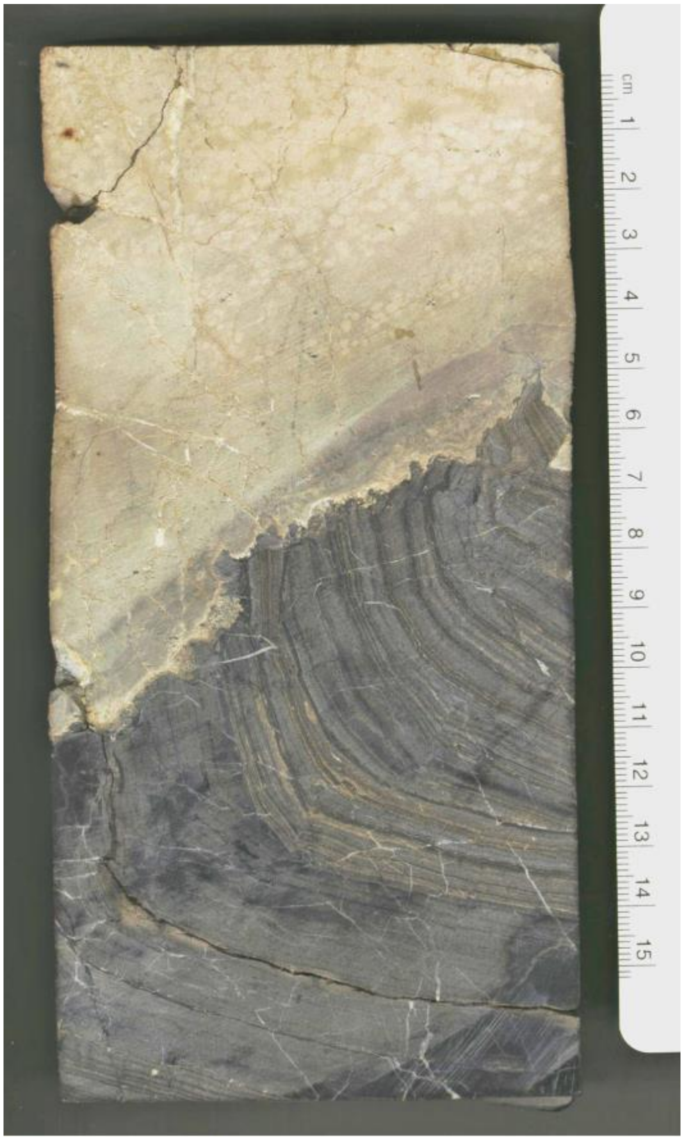


Figure 408. Deformed Smackover Limestone at the contact of a phonolite (71.6 Ma) intrusion in the Mississippi Valley Gas #1 Terry Bell in Washington County at a depth of 4,024 feet (MGS core box C-49.6). Picture made by James Starnes on a flatbed scanner. Image 813.

Figure 409. Granite pebble collected by Paul Parrish from the Mississippi River gravel bar at Rosedale, Mississippi. Picture (digital: Image 1778) was taken on November 17, 2010; scale in inches.

identify high radon potential areas in the United States. A radon screening project in Mississippi in 1991 projected that 3% of the state's homes had radon levels higher than 4 pCi/L. In June of 1992, the Office of Geology reviewed a draft of the "Preliminary Geologic Radon Potential Assessment of Mississippi" by Linda Gundersen. This draft was published in *EPA's Map of Radon Zones in Mississippi* (September 1993). A slightly earlier report by the Mississippi State Department of Health's Division of Radiological Health (*Mississippi Residential Radon Survey Final Report*, May 20, 1993) contained a section on the radon potential of Geologic and Soil Formations.

Radon in soil moves along a pressure gradient from high pressure in the cold/cool soil to low pressure in a warm house. When it encounters a home foundation, radon seeps through: (1) spaces between basement walls and slab, (2) cracks in foundations and/or walls, (3) openings around sump pumps and drains, (4) construction joints, (5) crawl spaces, and (6) showers and water faucets using domestic well water containing radon. Since soil conditions tend to be variable, radon levels may be high in one house but not in the house next door. Also, the design of the house is important; a home with a basement or slab foundation can accumulate higher levels of radon than a house on a conventional foundation with a ventilated crawl space beneath the subfloor.

There is no known safe level of radon exposure, but the risk can be reduced by lowering the radon level in the home environment. Radon mitigation for homes with basements, or built on concrete slabs, consists of depressurizing the soil beneath the slab or basement and walls. The cost of a sub-slab system in Mississippi is generally less than $2,000 and consists of a vent pipe system and fan that pulls radon from beneath the house and vents it to the outside. For further information, check Indoor Radon at the Mississippi Department of Health website.

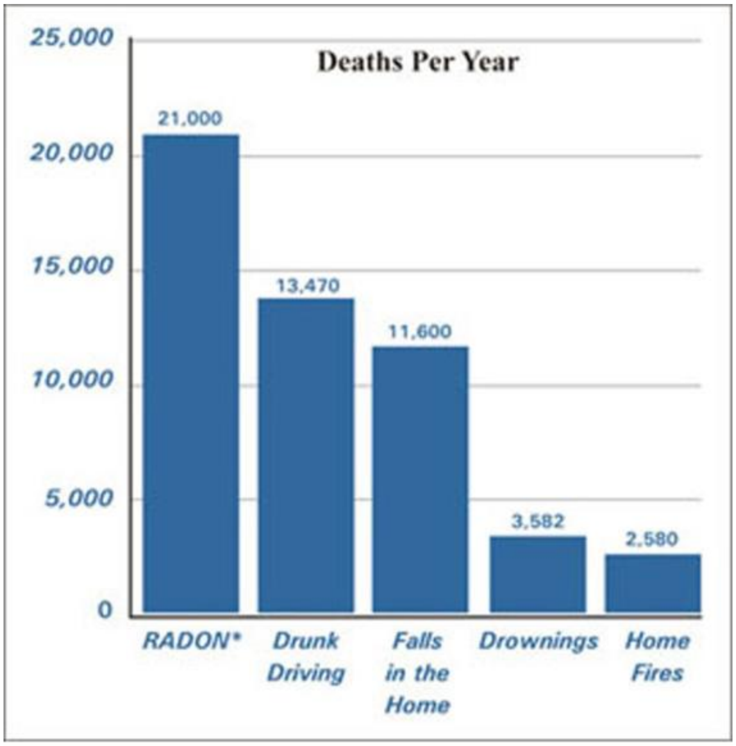


Figure 410. Radon is estimated to cause 21,000 lung cancer deaths per year, according to EPA's 2003 Assessment of Risks and Radon in Homes (EPA 402-R-03-003). The number of deaths from other causes are from the Centers for Disease Control and Prevention's 2005-2006 National Center for Injury Prevention and Control Report and 2006, National Safety Council Reports. Image 2141.

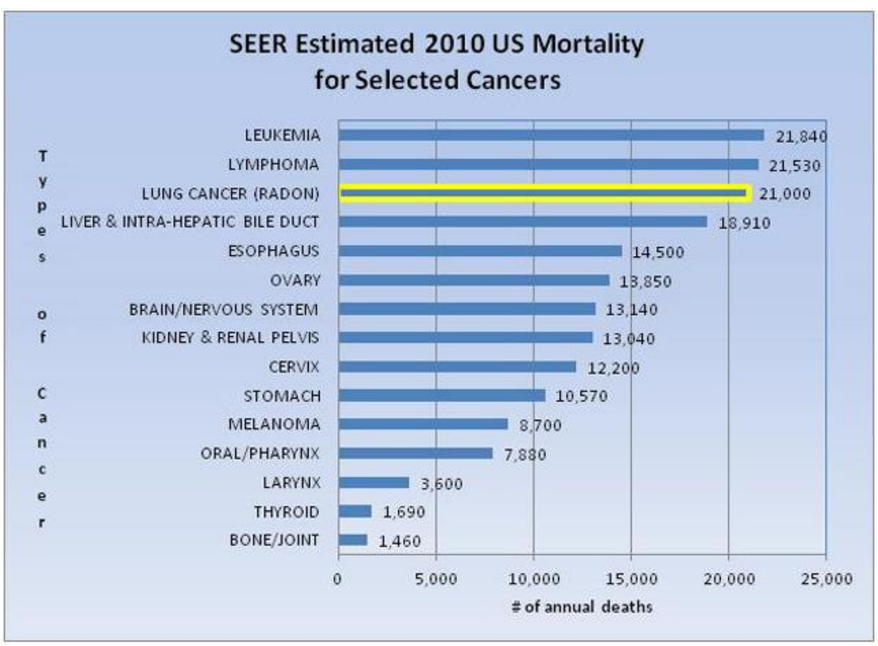


Figure 411. Number of deaths in 2010 from selected cancers as estimated by the National Cancer Institute, Surveillance Epidemiology and End Results (SEER). Image 2142.

SUPERFUND SITES

Superfund is a term for a fund established by the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) enacted by Congress in 1980 in response to a national outcry concerning over pollution and health issues reported in the 1970s at such sites as: (1) Love Canal in New York, (2) Times Beach, Missouri, and (3) the Valley of the Drum in Kentucky. Love Canal was the foremost of these sites. The canal was initially constructed by William T. Love in the early 1890s as a canal that would connect the Niagara River to Lake Ontario but later as a waterway for an urban area called "Model City" in a planned community of parks and homes. The canal was completed to a length of one mile, a width of 50 feet, and a depth of 10 to 40 feet. Model City was never realized, and, in the 1920, the canal became a dump site for the City of Niagara Falls. In 1942, Hooker Electrochemical Company (later known as Hooker Chemical Company) was granted permission to dump wastes in the canal. The company drained the canal and lined it with a thick clay seal. From 1942 till the dump closed in 1953, Hooker Chemical placed 55-gallon metal or fibre barrels containing some 21,000 tons of hazardous chemicals within the canal, and covered the drums with a 20- to 25-foot-thick clay and dirt seal. In 1947, Hooker Chemical bought the Love Canal dump site and the 70-foot-wide banks on either side.

The City of Niagara Falls experienced an economic and population boom after World War II, and the Niagara Falls City School District pressed Hooker Chemical to sell the dump site to the District. Hooker initially refused and then sold the property to the district for one dollar with an agreement that stated in part:

"Prior to the delivery of this instrument of conveyance, the grantee herein has been advised by the grantor that the premises above described have been filled, in whole or in part, to the present grade level thereof with waste products resulting from the manufacturing of chemicals by the grantor at its plant in the City of Niagara Falls, New York, and the grantee assumes all risk and liability incident to the use thereof."

Hooker Chemical also recommended that the area should be sealed off to prevent the possibility of persons or animals coming in contact of the buried chemicals. Disregarding these warnings, the school board began the construction of the 99th Street School at the site. When construction work uncovered two dump sites with 55 gallon drums, the school board moved the school some 80 to 85 feet to the north and removed a large part of the protective cap of the dump site for use as construction fill dirt. The school was completed in 1955 and had some 400 children, who played on the school grounds amongst puddles of chemicals from exposed drums. In 1957, the City of Niagara Falls constructed sewers and waterlines for low- and middle-income residences on the site. While digging the sewers, construction crews broke through the protective clay seals and breached the canal walls. In 1961, the LaSalle Expressway was constructed across Love Canal. This construction restricted the flow of ground-water flowing to the Niagara River and caused the water table to rise within the breached chemical dump, creating an overflowing pool in the wet winter and spring of 1962.

In 1976, reporters for the *Niagara Falls Gazatte* tested water from sump-pumps near Love Canal and discovered toxic chemicals. Later in 1978, a reporter surveyed the community and found birth defects and anomalies such as enlarged feet, heads, hands, and legs. Such reports made the national news as an environmental disaster. On August 7, 1978, President Jimmy Carter announced a federal health emergency (the first of its kind) and ordered the Federal Assistance Agency to assist the City of Niagara Falls in remedying the Love Canal site. An inspection of the site found the carcinogen benzene and found dioxin (polychlorinated dibenzodioxins), a carcinogen which is usually measured in part per trillion but was measured at 53 parts per billion at Love Canal. In 1979, EPA reported a high rate of miscarriages in the Love Canal community and discovered toxic materials in the milk of nursing mothers. The government eventually relocated 800 families and reimbursed them for their homes. In 1995, Occidental Petroleum (the new name for Hooker Chemical) settled a lawsuit by the EPA with an agreement to pay $129 million in restitution, after a federal district judge ruled that Hooker/Occidental was negligent but not reckless in the sale of its Love Canal dump site to the Niagara Falls School Board.

Remediation of the site included reburying the chemicals on site within a thick plastic liner and a seal of clay and dirt (in a similar fashion to the dump's originally constructed before the seals were breached). A 2.4-meter-high barbed wire fence was constructed around the reconstructed dump site. In 1980, Dr. Lewis Thomas of Memorial Sloan-Kettering Cancer Center and Chairman of Governor Hugh Carey's panel of scientist investigating

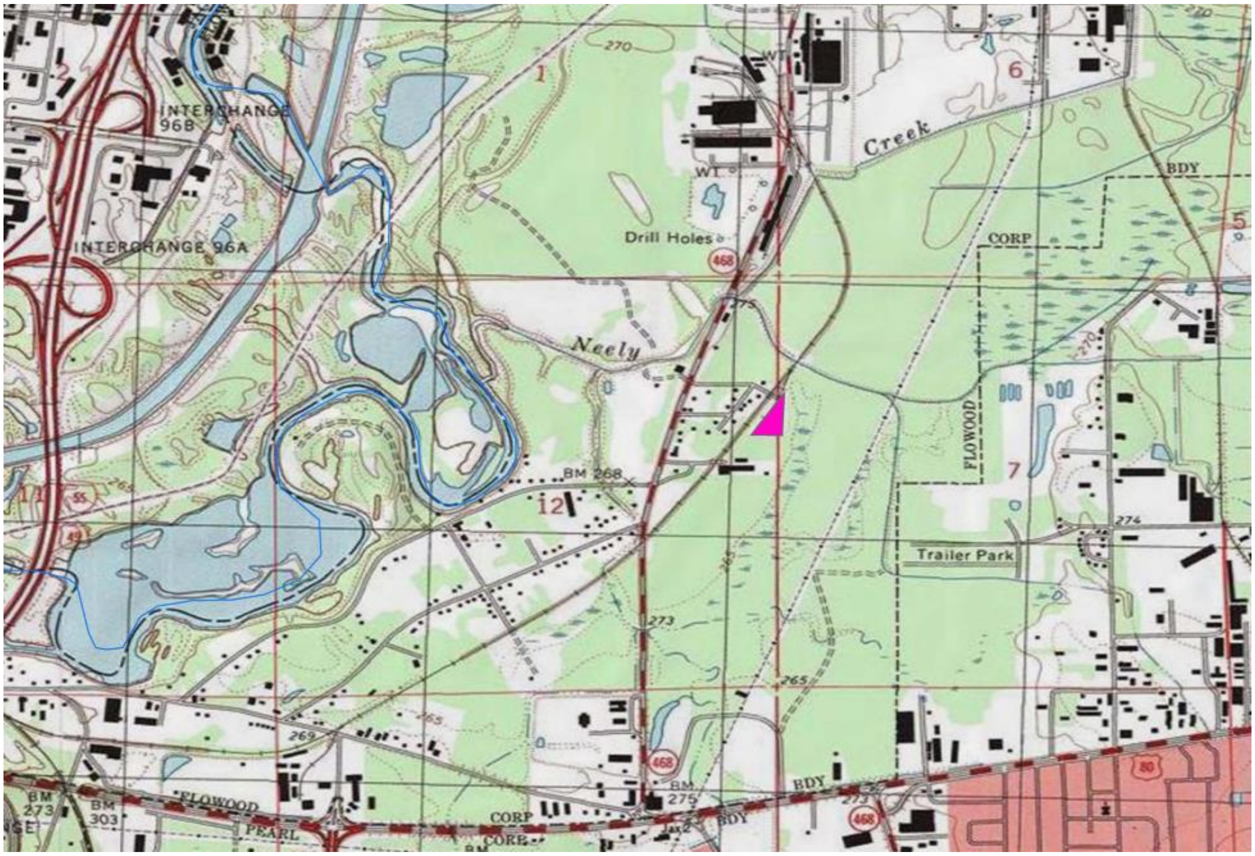


Figure 412. Location of the Sonford Superfund site (pink triangle east of Highway 468 on the Section 12-Section 7 boundary line) on the Jackson 7.5-Minute Quadrangle map. Image 2147.

Figure 413. Location of the Sonford Superfund site (triangle with McMillon, Dalton, & Aileen property) on an areal photograph with property lines in yellow. Image 2148.

Figure 414. Navigating the direct push technology well installer across the Sonford Superfund site at Flowood, Mississippi. Picture (digital; Image 2149) was taken by Richard Ball on September 5, 2007.

Figure 415. Water well installation at the Sanford Superfund site by workers from EPA's Southeastern Scientific Division using direct push technology. Picture (digital: Image 2150) was taken by Richard Ball on September 5, 2007.

Love Canal declared, "as a result of this review, the panel has concluded that there has been no demonstration of acute health effects linked to exposure to hazardous wastes at the Love Canal site. The panel also concluded that the chronic effects of hazardous wastes exposure at Love Canal have neither been established or ruled out yet." In 1998, an editorial by Dr. Elizabeth M. Whelan stated that the people of the Love Canal community fell ill, not because of the chemicals, but because the media created hysteria by calling the site a "public health time bomb." Dr. M. Whelan asked and answered the question: "Was there ever any real health problem at Love Canal? Yes, there was, in the sense that there was an enormous amount of media-induced stress placed on residents who were terrified that they and their children would become ill. But no—there was never any documented evidence that exposure to chemicals at the site caused death or disease."

Sonford International and Sonford Products Superfund Site

Site History. The Sonford Products Superfund Site is located at 3506 Payne Drive in Flowood in Rankin County, Mississippi (**figures 412-413**). The site at present contains six acres used the construction of fiberglass and later concrete septic tanks. On this site are work buildings, an apartment complex with five apartment units, and a single-wide mobile home. In 2006, five people resided on the Sonford property, three in apartments and two in the mobile home.

Two chemical processing plants, Sonford International and Sonford Products, were operated on the site from 1972 to 1985. Both operations involved turning solid pentachlorophenal (PCP) into liquid formulations. From 1972 to 1980, Sonford International produced sodium pentachlorophenate, a water-soluble product used for the short-term protection of wood products from mildew. From 1980 to March 1985, Sonford Products produced an oil -soluble PCP product used for the long-term protection of wood products and also produced products for pest control and products to control the growth of mold and sap stains in freshly cut wood. Sonford Products closed in April of 1980 due to allegations that an employee died as the result of poisoning from high exposure levels of PCP.

An inspection of the Sonford Products site by the Mississippi Department of Environmental Quality on December 31, 1980, identified 550 pounds of PCP and 6,000 pounds of sodium pentachlorophenate. The waste product from PCP production was a sludge that was stored in drums on the site. These drums of waste were sent to Chemical Waste Management in Emelle, Alabama, for disposal. The sodium pentachlorophenate was shipped to the Sonford facility in St. Paul, Minnesota, for reuse.

On April 18, 1985, approximately 2,000 gallons of PCP were spilled into the wetland south of the property when someone turned on valves to the storage tanks during the night. The first Bureau of Pollution Control responder was the Bureau Head, Charles Chi-

Figure 416. Two-inch core samples taken by direct push technology at the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2151) was taken by Richard Ball on September 6, 2008.

Figure 417. Two-inch cores of Pearl River alluvial sands taken by direct push technology on the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2152) was taken by Richard Ball on September 6, 2008.

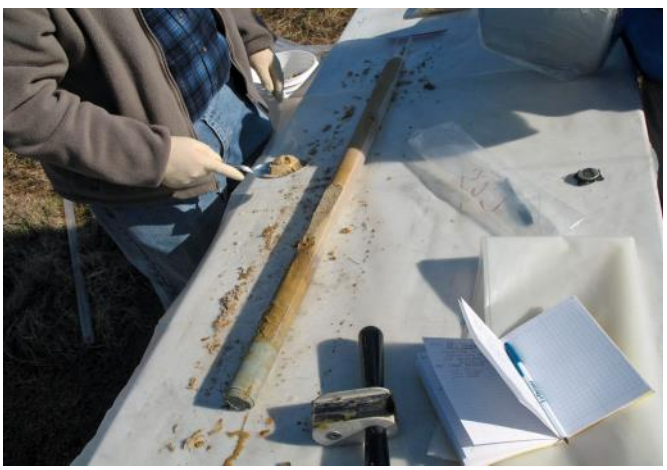


Figure 418. Direct push technology core from the Sonford Superfund site in Flowood, Mississippi. Brown Pearl River alluvial sands overlie a section of blue-gray Yazoo Clay at the bottom of the core. Picture (digital; Image 2153) was taken by Richard Ball on February 6, 2008.

solm, who turned the valves off. The wetland was found to be contaminated with PCP, mercury, lindane, and phenylmercuric acetate. EPA took responsibility for remediation at the Sonford site on April 21 and 22, 1985. Some 2,500 cubic yards of contaminated soil were transported to the chemical waste facility at Emelle, Alabama, and 10,000 gallons of oil and treating solution were incinerated at a waste facility in South Carolina. Some 100,000 gallons of wastewater on the site were treated and disposed. EPA remedial action for the 2,000 gallon PBC release was completed on May 10, 1985.

On May 9 and 10, 1985, three groundwater monitoring wells (SP-1 through SP-3) were installed at the Sonford site; SP-1 was a background well for comparison to SP-2 and SP-3. The Mississippi Bureau of Pollution Control maintained and monitored the three wells. In November of 1985, wells SP-2 and SP-3 were found to have elevated levels of inorganic compounds, with significant elevations in selenium as compared to well SP-1.

In 2004, Weston Solutions, Inc. prepared a Preliminary Assessment/Site Investigation for the Sonford site to determine if the site had the potential to be placed on the National Priorities List. Samples were taken of the surface soil, subsurface soil, ground water, and sediments. These samples contained elevated levels of cadmium, lead, nickel, mercury, and zinc. Some samples could not be taken due to elevated concentrations of volatile organic compounds in the breathing zone. Samples collected by Weston in April of 2005 found elevated concentrations of pesticide, dioxin, and dibenzofuran in the PCP processing area of the Sonford site. In 2007 and 2008, additional monitor wells were installed on the site (**figures 414-416**), core samples were taken (**figures 417-418**), and more soil samples were taken for analyzes (**figures 419-420**). The toxicity of the soil was tested by diluting the soil with earthworm-friendly admixtures and then seeing if the earthworms could live in it. None of the earthworms placed in the soil survived.

Site Geology. Fourteen temporary wells were installed in the shallow aquifer at the site, and one deep well was installed to a

Figure 419. EPA workers taking soil samples with a hand auger on the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2154) was taken by Richard Ball on February 5, 2008.

Figure 420. EPA workers taking soil samples on the Sonford Superfund site in Florwood, Mississippi. Picture (digital; Image 2155) was taken by Richard Ball on February 5, 2008.

Figure 421. Rotosonic drilling rig adding another drill stem at the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2156) was taken by Richard Ball on September 10, 2008.

Figure 422. Rotosonic drilling rig and pipe truck parked at the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2157) was taken by Richard Ball on September 9, 2008.

depth of 227 feet using a Rotosonic drill rig. The site is on the Pearl River alluvial plain and is underlain by 20 to 25 feet of Pearl River alluvial sand, silt, and clay. This alluvium comprises a shallow unconfined aquifer. Below the Pearl River alluvium is Moodys Branch Formation with perhaps a thin remnant of the basal Yazoo Clay above it. Where the Yazoo Clay is absent, the alluvial aquifer and the Moodys Branch aquifer are in hydrologic contact. The water table in the alluvial aquifer was found to range from 255.00 to 255.94 feet above sea level, and the general groundwater flow was northwestward across the site. **Figure 414-416** shows the coring process on the site using direct push technology. **Figure 417-418** shows cores of the Pearl River alluvial sand.

The Sonford site is high on the southeastern flank of Jackson Dome in an area where the top of the Moodys Branch Formation is higher than 225 feet above sea level (Baughman, 1971, pl. 3). Ground level at the site is 265 feet above sea level, and the top of the Moodys Branch Formation (and the base of the Yazoo Clay) is 28 feet below the surface. The "Log of Boring" done by Black & Veatch for the deep Rotosonic test hole (**figures 421-422**) in September of 2008 gave a general soil

Figure 423. Four-inch core of the Cockfield Formation from the Sonford Superfund site in Flowood, Mississippi. Fossil plant remains can be seen where the core is parted. Picture (digital: Image 2158) was taken by Richard Ball on September 10, 2008.

Figure 424. Fossil plant remains in a four-inch core of the Cockfield Formation from the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2159) was taken by Richard Ball on September 10, 2008.

Figure 425. Installing an injection well with an auger rig at the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2160) was taken by Richard Ball on August 19, 2011.

Figure 426. Installing tubing and well head for an injection well at the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2161) was taken by Richard Ball on September 19, 2011.

description for each ten-foot core section, showing artificial boundaries at ten-foot intervals. The log information was not very helpful in picking formational boundaries. Two test holes that were very helpful were drilled on March 14 and 15, 2012, and took split-spoon cores at five-foot intervals. These samples were examined, and consisted of: (1) Pearl River alluvium to about 28 feet, (2) from 28-30, the upper Moodys Branch Formation, (3) from 33-35 feet, the Moodys Branch Formation with a concretion at 33 feet, (4) from 38-40 feet, a gray silty fossiliferous clay from the Creola Member of the upper Cockfield Formation, (5) from 40-42 feet, a Shelby-tube sample with gray clay and silt of the upper Cockfield Formation and no fossil shells. Pictures of one of the Rotosonic cores that shows the typical lithology of the upper Cockfield Formation is in **figures 423-424**. An inter-core boundary was recognized in the Rotosonic Cockfield core from 210 to 220 feet, which consisted of ‘Dark brown silty CLAY, tight, dry from 210 to 215 feet, and “Brown silty SAND, coarse-grained wet” from 215 feet and extending to 225 feet in the next core. This sand comprises the upper Cockfield aquifer. The Town of Flowood well #2, which is near

Figure 427. Well field for pilot test site at the Sonford Superfund site. Well 1 in the middle is the recovery well. On the four perimeter corners are injection wells 2-5. An interior set of four piezometer wells are numbered 6-9. Picture (digital; Image 2162) was taken by Richard Ball on September 19, 2011.

Figure 428. Holding tank and four lines leading to the injection wells. A surfactant is being injected into the Pearl River alluvial aquifer at this time. It is the first of three chemical mixes to be injected. Picture (digital; Image 2163) was taken by Richard Ball on September 19, 2011.

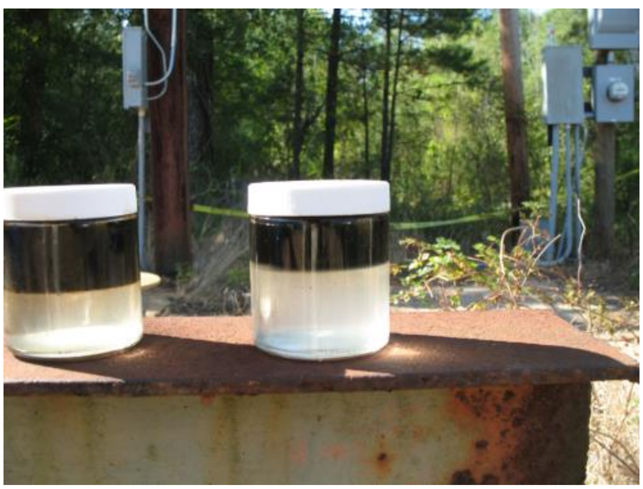


Figure 429. Water samples taken before the injection of surfactant into the Pearl River alluvial aquifer. The black liquid at top is a pure pentachlorophenal (PCP) and solvent mix floating on ground water. Picture (digital: Image 2164) was taken by Richard Ball on September 22, 2011.

Figure 430. Water sample taken after the injection of surfactant, showing no separation between the pentachlorophenal (PCP) and solvent mix and the groundwater. Picture (digital: Image 2165) was taken by Richard Ball on September 19, 2011.

the site and at the same elevation, encountered 35 feet of sand in this aquifer at 170 to 215 feet below surface level. The core below 215 feet and to the base of the core hole at 227 feet was described as "Dark brown to black sandy CLAY with small amount of pebble size grains, wet."

Pilot Study. In August and September of 2011, a pilot study was conducted for injecting an oxidizer (sodium persulfate) into the Pearl River alluvial aquifer. The purpose of the study was to test the potential of an oxidizer to break down PCPs into non-toxic materials within the aquifer. To accomplish this, a series of injection wells, monitor wells, and a central recovery well were installed in the most polluted area of the site (**figures 425-427**). The pilot test included three injection phases. The first was the injection of a surfactant to disperse the PCP-solvent mix in the groundwater (**Figure 428**). Dispersal of the PCP-solvent mix provided a greater surface area for oxidation. **Figures 429-430** compare the non-dispersed samples, where the PCP solution is strongly separated from the water, with the dispersed PCP ground-water mix . **Figure 431** shows the dispersed PCP mix in a half-inch-diameter bailer

Figure 431. Half-inch bailer sample of the water column from a monitor well at the Sonford Superfund site in Flowood, Mississippi, taken after the injection of surfactant. The black column of pentachlorophenal (PCP) and solvent is partially mixed with the ground water. Picture (digital:; Image 2166) was taken by Richard Ball on September 20, 2011.

Figure 433. Industrial strength caustic soda (sodium hydroxide) on the Sonford Superfund site in Flowood, Mississippi, in preparation for injection into the polluted Pearl River alluvial aquifer. Picture (digital; Image 2168) was taken by Richard Ball on September 19, 2012.

Figure 432. Mixing sodium persulfate, an oxidizer, to be injected into the ground water through four injection wells on the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2167) was taken by Richard Ball on September 20, 2011.

Figure 434. Testing ground water from the recovery well to make sure the sodium hydroxide injected through the injection wells has produced a pH of 14 or 15. The color match indicates a pH of 14. Picture (digital; Image 2169) was taken by Richard Ball on September 22, 2011.

sample from a monitor well. The second injection phase was the injection of the oxidizer sodium persulfate (**Figure 432**). Sodium persulfate is preferred as a oxidant because of its high solubility in water and because its reaction with contaminants leaves less harmful side products. Sodium persulfate can degrade many environmental contaminants by itself, but it is generally used with other agents, such as heat, ultraviolet light, high pH, hydrogen peroxide, and transmission metals to activate persulfate ions and generated sulfate radicals (SO_4^-). The third injection phase was the injection of caustic soda (sodium hydroxide) (**Figure 433**). The purpose of the caustic soda was to increase the ground water pH to 14 or 15 (**Figure 434**) and react out the sodium persulfate to release oxygen. This reaction changes the PCP plume in the groundwater into a chloride (salt) plume, which is much less toxic. A report on the effectiveness of this pilot test is pending. Information of the Sonford Superfund site history given here is from the *Draft Remedial Investigation Report, EPA Contract #68-W-99-043* (February 2009), and information and pictures on the pilot test are from Richard Ball of the Mississippi Office of Pollution Control.

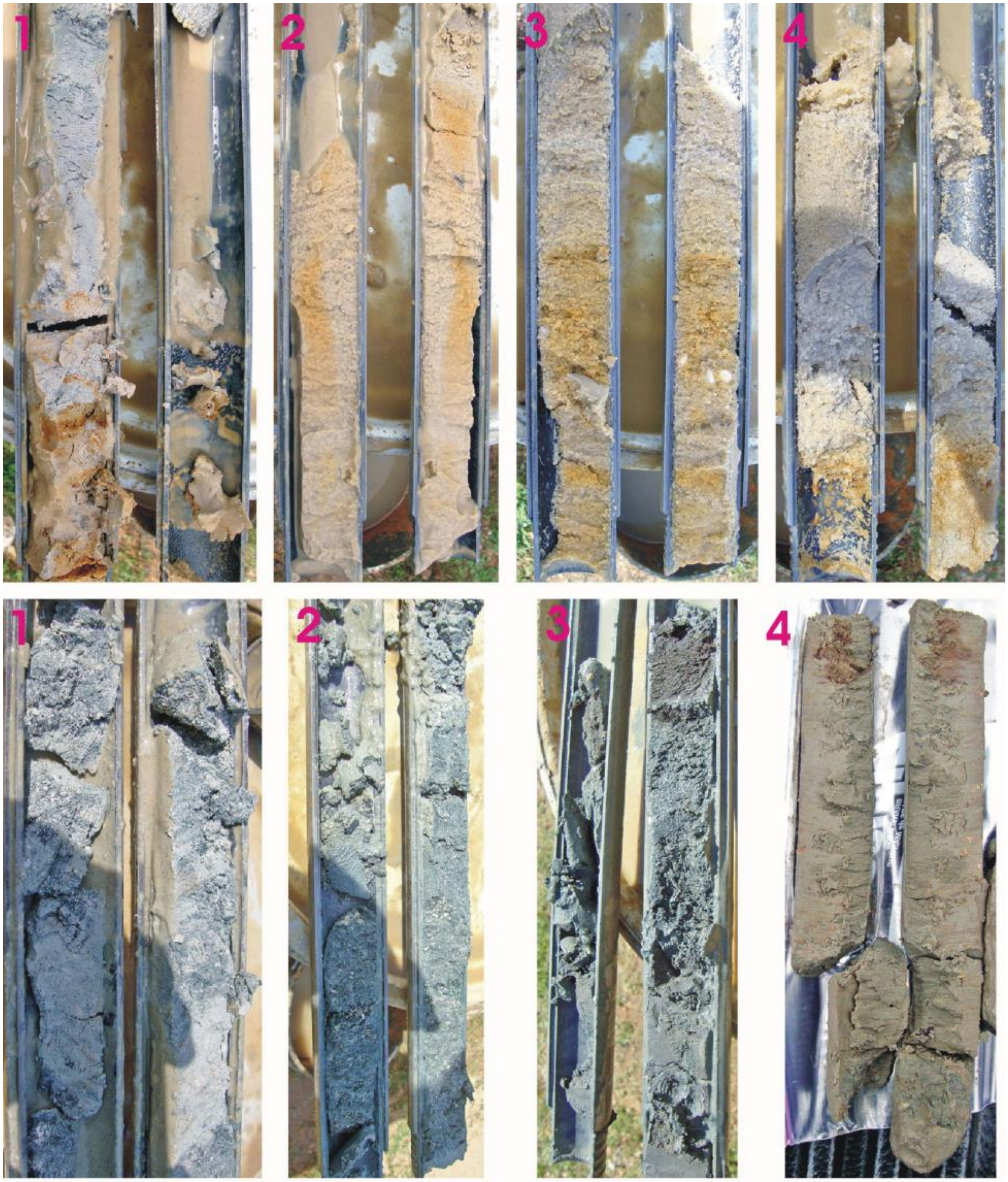


Figure 435. Stratigraphy of the Sonford Superfund site in Flowood, Mississippi, as show in 2-foot spilt-spoon cores. At top are cores from the Pearl River alluvial sand: (1) fine-grained sand from 8-10 feet, (2) medium-grained sand from 13-15 feet, (3) medium– to coarse-grained sand with quartz pebbles from 18-20 feet, and (4) medium– to coarse-grained sand at 23-25 feet. At bottom are: (1) fossiliferous clayey sands of the upper Moodys Branch Formation at 28-30 feet, (2) fossiliferous sands of the Moodys Branch Formation from 33-35 feet, (3) chocolate-gray silty clay and fossiliferous sands of the Creola Member of the upper Cockfield Formation from 38-40 feet, and (4) gray silty clay of the Cockfield Formation from 43-45 feet. The last core of the Cockfield Formation was from the first drill site completed on March 14, 2012. The others are from the second drill site completed on March 15, 2012. Image 2217.

Figure 436. Hammering the split-spoon core tube into the ground at 18-20 feet below the surface at the second drill site on the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2218) was taken on March 15, 2012.

Figure 437. Recovering a split-spoon core form 38-40 feet at the second drill site on the Sonford Superfund site in Flowood, Mississippi. Picture (digital; Image 2219) was taken on March 15, 2012.

Figure 438. Workers are laying out and unfolding a very large mat at the Sonford Superfund site in Flowood, Mississippi, on which contaminated soil from an adjacent residential area will be placed before the its permanent burial in a disposal cell on site. Picture (digital; Image 2220) was taken on April 13, 2012.

Figure 439. Digging up the yards of residents near the Sonford Superfund site. The dirt excavated is contaminated with pentachlorophenol (PCP). It will be replaced with dirt "clean enough for children to eat." Picture (digital; Image 2221) was taken on April 18, 2012.

Split-spoon samples from test holes drilled at the disposal cell site on March 14 and 15, 2012, are shown in **Figure 435**. **Figures 436-437** show, respectively, driving (hammering) down the split-spoon core and core recovery. **Figure 438** shows the layout of the mat (partially unfolded in the picture) on which contaminated soil will be placed. **Figure 439** shows the excavation of soil from a residential yard contaminated with pentachorophenol (PCP), which will be transported to the mat adjacent the permanent disposal site (**Figure 425**) and replaced with uncontaminated soil.

In December of 2012, a new survey was made of the pentachlorophenate plume at the Sonford site. To accomplish this, a team was assembled at the site under the management of Black & Veatch with equipment and personnel from across the Southeast. A track-mounted direct-push-technology rig with a laser-induced fluorescence (LIF) probe was used to detect PCP in the groundwater column.

Figure 440. PCP contaminated top soil from neighborhood yards under tarp at the Sonford Superfund site. Picture (digital; Image 2271) was taken on December 5, 2012.

Once the LIF log was completed for a location, a track-mounted direct-push-coring rig sampled the alluvial section at the same spot for laboratory analysis (**Figure 441**). **Figure 442** shows the operation of the direct-push LIF rig. **Figure 443** shows a LIF probe and a core from a depth of 10-15 feet with dark bands of PCP contaminants. The LIF log printout is given in **Figure 444** and the 2010 PCP plume map in **Figure 445**.

Figure 441. Direct-push 5-foot-long cores from the PCP plume area; core 1 is fill dirt, 2-5 alluvium, 6-9 Moodys Branch Formation. Picture (digital; Image 2272) was taken on December 5, 2012.

Figure 442. At left, a track-mounted direct-push device has hammered through the concrete slab of a metal shed and in now hammering a LIF probe through the Pearl River alluvium at the Sonford Superfund site at Flowood, Mississippi. At right, site engineer Darci Scherbak checks the 2010 plume map against the real-time LIF log for 2012. Pictures (digial; Image 2273) were taken on December 5, 2012.

Figure 443. At left, laser-induced fluorescence (LIF) probe; the green laser light is shinning through a sapphire window in the middle at top. At right, a LIF log at bottom, showing contaminants at depths of 10-15 feet, and the 10-15-foot core just above, showing dark bands at high levels of PCP concentrations. The “sweet” smell of PCP in the core was very strong. Pictures (digital: Image 2274) were taken on December 5, 2012.

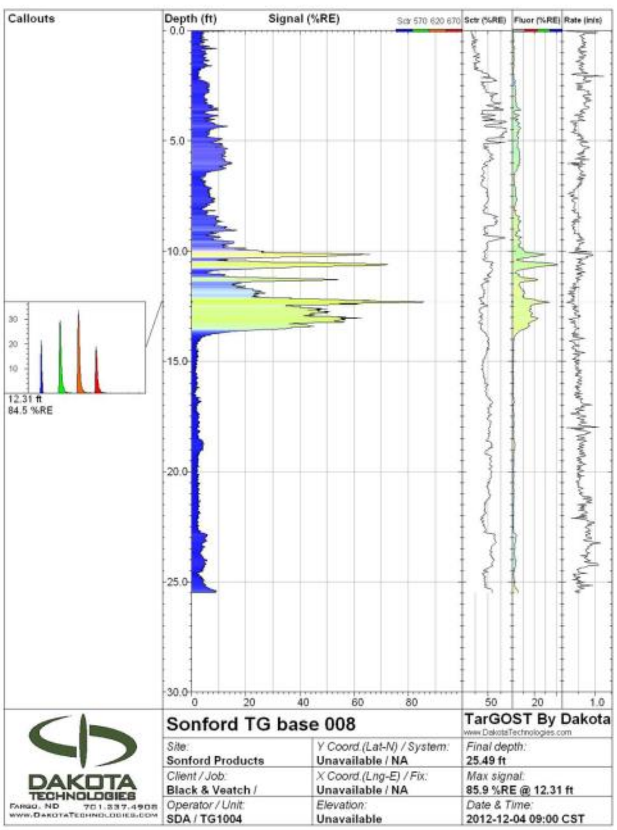


Figure 444. LIF log of Sonford TG base 008 location (as seen in Figure 408), showing PCP contamination between 10 and 15 feet in the Pearl River alluvial aquifer. Image 2275.

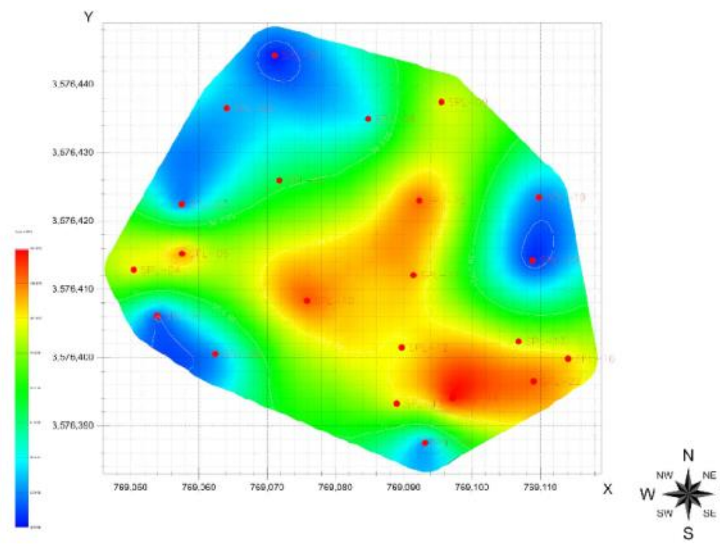


Figure 445. PCP plume map from fieldwork completed at the Sonford site in 2010, from *Environmental News*, February 2013, p. 20. Image 2276.

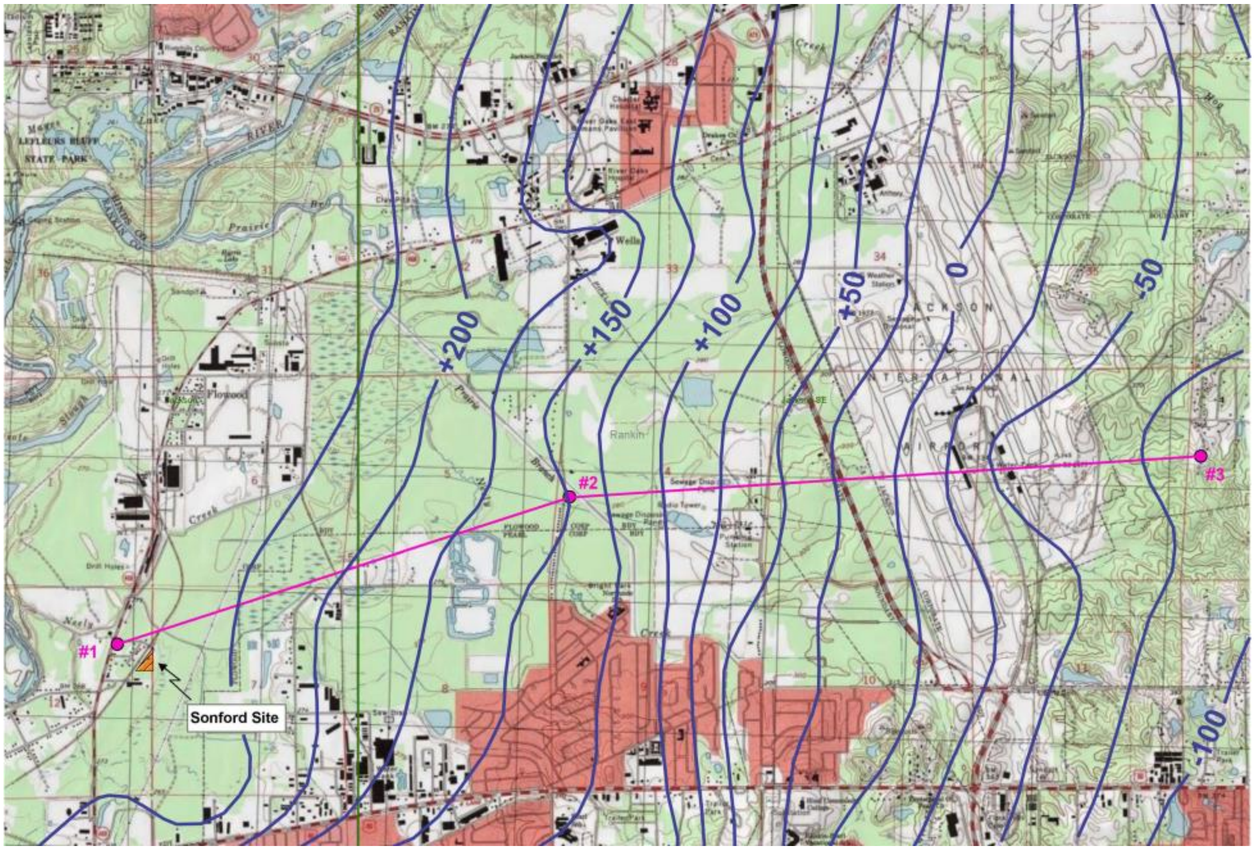


Figure 446. Location map of cross section and the Sonford Superfund site on portions of the Jackson and Jackson SE 7.5-minute topographic quadrangle maps. Contours on the top of the Moodys Branch Formation are shown in blue with the "0" contour at sea level; contours rise from 100 feet below sea level (east) to 225 above sea level (west) for a total rise in this map view 325 feet. Beyond the 225 contour, and before the place for the 250 contour, the base of the Yazoo Clay is truncated beneath the Pearl River alluvium, and the Moodys Branch is either difficult to pick on geophysical logs or is missing due to erosion. The base of the Pearl River alluvium at the Sonford site is about 240 feet above sea level. Contours are by Wilbur T. Baughman (1971, Plate 3) from *Rankin County Geology and Mineral Resources*: Mississippi Geological Survey, Bulletin 115. Figure from *Environmental News*, February 2013, p. 21. Image 2277.

Protecting Groundwater Aquifers and Water Supplies. The steep rise of the Moodys Branch and Cockfield aquifer sands were not realized during the first phases of work at the Sonford site. The early assumption was that a thick sequence of Yazoo Clay protected the underlying aquifers from contamination. **Figure 446** shows the location of two water wells and an intermediate test hole used in the cross section in **Figure 447**. The Moodys Branch rises some 450 feet from east to west on the eastern flank of the Jackson Dome and underlies an old terrace of the Pearl River Alluvium at the Sonford site. As the pollutant is lighter than water, there is less chance of polluting aquifer sands in the Moodys Branch formation.

In February 2014, work began on the construction of a well field, with both screened wells and vent wells, within the plume to draw off the pollutant. (**Figure 448-451**). Earlier work to react out the pollutant with chemical injections was only partially successful due to the large volume of the pollutant in the surficial aquifer. Once the well field was complete, a concrete slab was installed around the well heads to give a clean solid working surface and to prevent any spills from entering the soil.the surface. A metal shed on the site was modified to house pumps and separators to remove pollution products from the groundwater.

Pumping of the polluted interval of the Pearl River Terrace aquifer began on June 9, 2014. **Figures 452-453** show the vent wells and 8 withdrawal well in Zone 1 of the pollution plume. **Figure 454** shows the hose connections of the wells to the vacuum mainline leading to the product separators in the metal building, where surfactant is added to emulsify the product and aid in the separation process. **Figure 455** shows the equipment in the metal building, including the surfactant storage, sep-

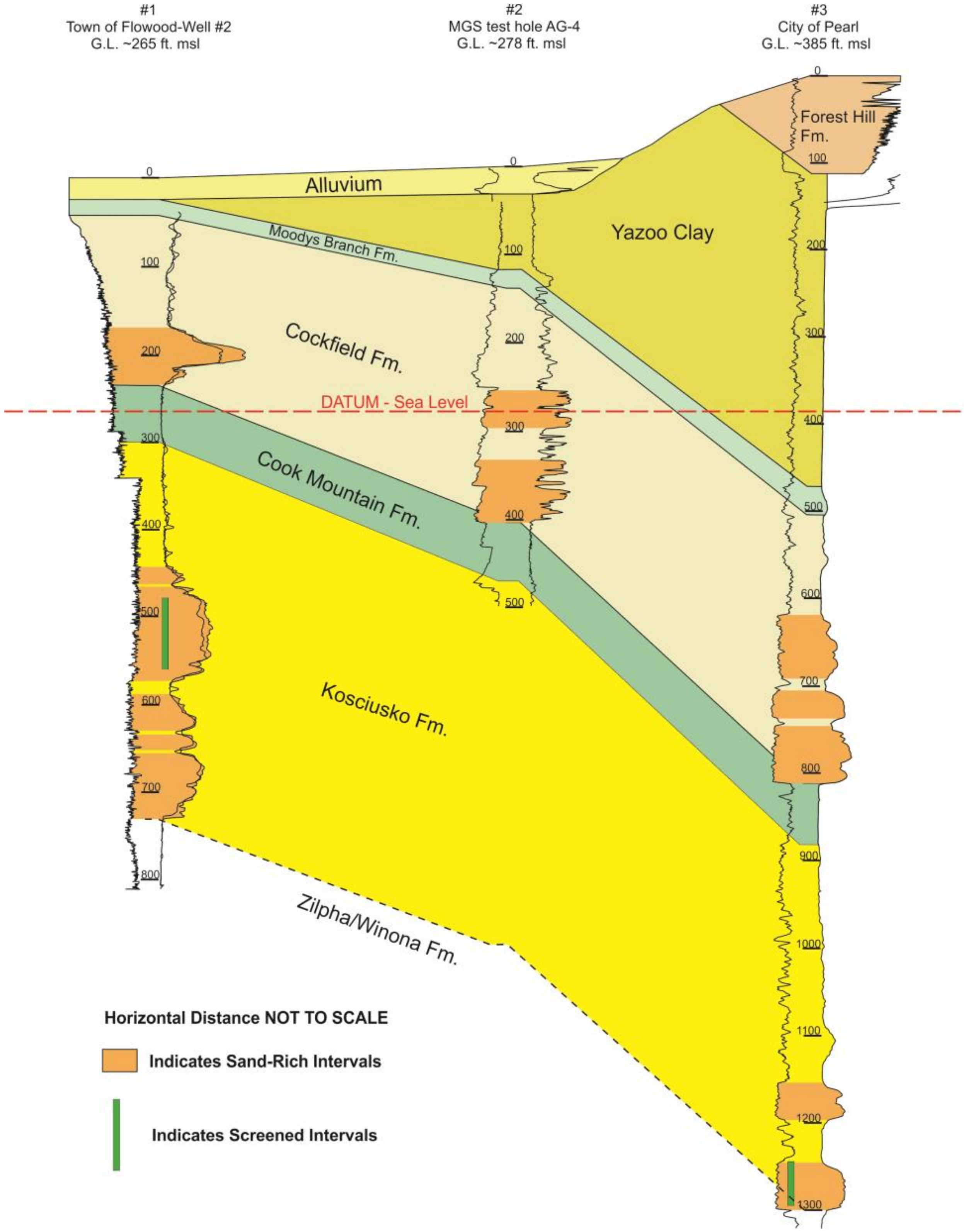


Figure 447. East-west cross section of wells on the eastern flank of the Jackson Dome, showing the westward truncation of the Yazoo Clay and Forest Hill Formation along the outcrop and beneath the Pearl River alluvium. Well #1 (Town of Flowood Well #2) is located just northwest of the Sonford Superfund site, where the Moodys Branch Formation directly underlies the Pearl River alluvium. Figure from *Environmental News*, February 2013, p. 22. Image 2278.

Figure 448. Auger drilling of a 25-foot-deep screened well in the pollutant plume at the Sonford site. Picture (digital; Image 2477) was taken on February 3, 2014.

Figure 449. Once the plug at the bottom of the bit is punched out, the screened well casing is lowered down the hollow center of the auger flight. Sand bags, containing the sand packing, sit next to the bore hole. Picture (digital; Image 2478) was taken on February 3, 2014.

Figure 450. Once the screened well casing is in place, the auger flights are raised and dismantled in five-foot sections as the sand packing is poured down the hole, filling the gap between the casing and formation left by the removed pipe. Picture (digital; Image 2479) was taken on February 3, 2014.

Figure 451. Screened well casing and sand packing in place within the pollutant plume at the Sonford sit. Picture (digital; Image 2480) was taken on February 3, 2014.

arators, and product storage tank. **Figure 456** shows the carbon-filter tanks for the separated water, which, once filtered, is returned to the aquifer. According to the contractors, the filtered water was clean enough the meet drinking water standards.

Figure 457 shows one of the injection wells. These wells were placed at the edge of the pollution plume. Thus, purified water from the plume added in driving the plume toward the withdrawal wells. Along each step of this process are water-sampling spigots to check the efficiency of product separation and water purity.

Figure 452. Zone 1 well field at the Sonford site. Hoses are attached to withdrawal wells; vent wells are at left. Picture (digital; Image 2481) was taken on June 13, 2014.

Figure 453. Richard Ball stands beside a withdrawal well at the Sonford site. Picture (digital' Image 2482) was taken on June 13, 2014.

Figure 454. Mainline connection leading to product separators in metal building. Picture (digital; Image 2483) was taken on June 13, 2014.

Figure 455. Surfactant container (with red label at back) and product separators (right front in blue) and product storage container (brown at left) in metal building at the Sonford site. Picture (digital; Image 2484) was taken on June 13, 2014.

Figure 456. Carbon-filter tanks capable of bringing separated water up to drinking water standards before it is returned to the aquifer in the injection wells. Picture (digital; Image 2485) was taken on June 13, 2014.

Figure 457. Injection well with pressure gauge. Injection wells were placed at the margin of the plume to drive pollutants toward the withdrawal wells. Picture (digital; Image 2486) was taken on June 13, 2014.

Davis Timber Superfund Site

Site History. The Davis Timber Superfund Site is located on Jackson Road, about 6 miles northwest of Hattiesburg, in a rural area of Lamar County, Mississippi. Davis Timber Company produced treated pine poles, pilings, and timber at the site from 1972 to 1987 (**Figure 458**). Company operations at the site included bark removal, treatment of wood with pentachorophenol (PCP), and product storage. The site covers about 30 acres on which were located a skag mill, debarder, pole peeler, office and shop, treatment cylinder, cooling pond, oil storage tank, two aboveground PCP-solution storage tanks, a storage yard, and a large former PCP and waste bark impoundment (**Figure 459**). Wastewater containing PCP and dioxin and furan compounds from site operations was discharged into the impoundment. In 1980, the impoundment was backfilled and capped by the property owner with 6 to 8 inches of clay.

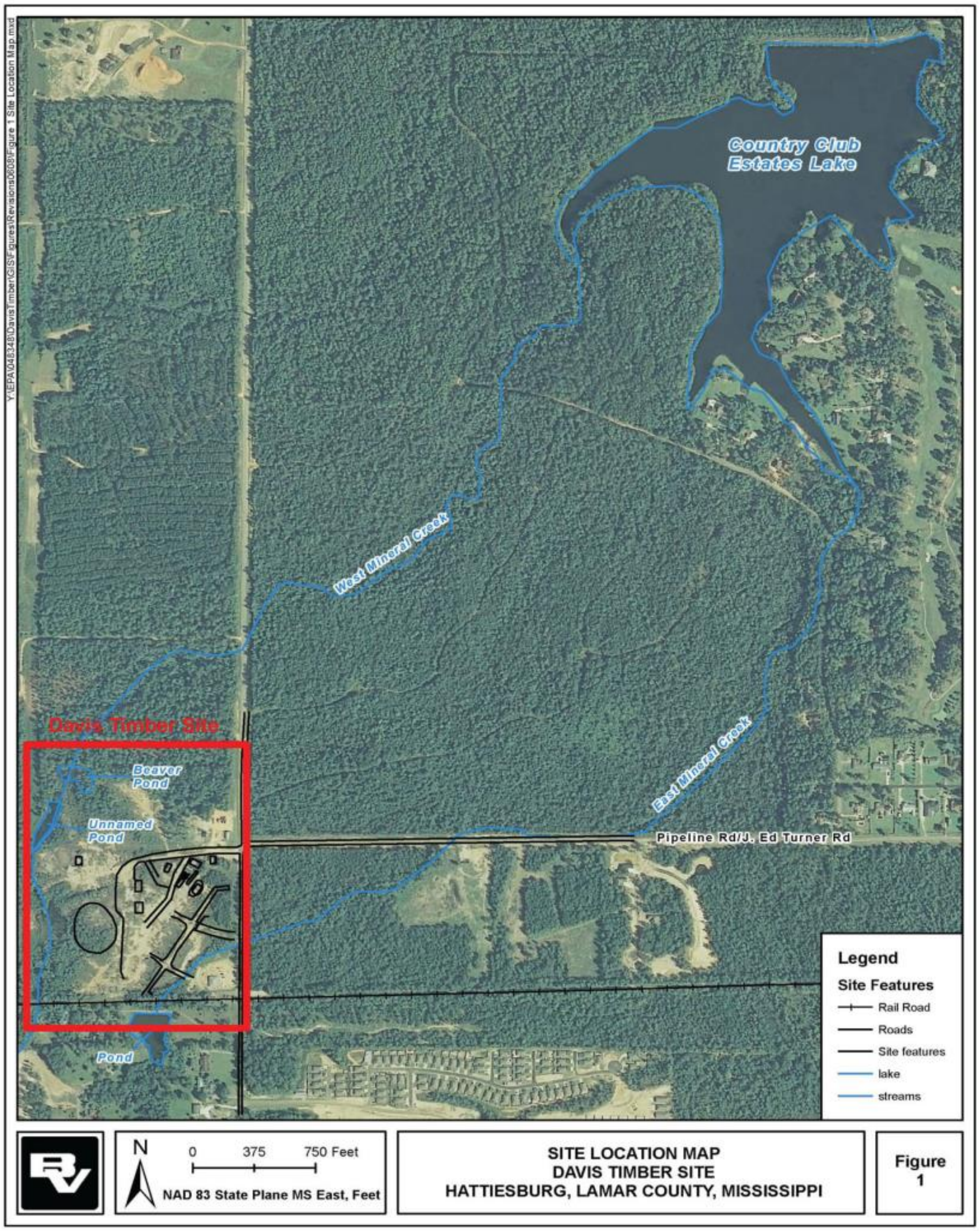


Figure 458. Location of the Davis Timber Superfund site. Image 2170.

Between December 1974 and January 1987 there were six fish kill in nearby Country Club Lake, several of which were attributed by the Mississippi Department of Environmental Quality (MDEQ) to documented releases of PCP from the impoundment. MDEQ ordered Davis Timber Company to discontinue wood preserving operations in 1987. The company declared bankruptcy in 1990. Debarking operations were continued on the site by Lamar Industries. The site is currently not in operation.

In 1989, MDEQ issued an advisory against consuming fish caught in Country Club Land due to high levels of dioxin compounds in the fish. This ban was lifted in June of 2001, after dioxin levels showed a significant decrease over a 10-year period. The site was proposed as a National Priorities List (NPL) site on May 11, 2000, and was finalized as an MPL site in July 2000 (**Figure 460**). The Science and Ecosystem Support Division (SESD) of EPA Region 4 conducted Remedial Investigations (RI) between 2000 and 2002 to charac-

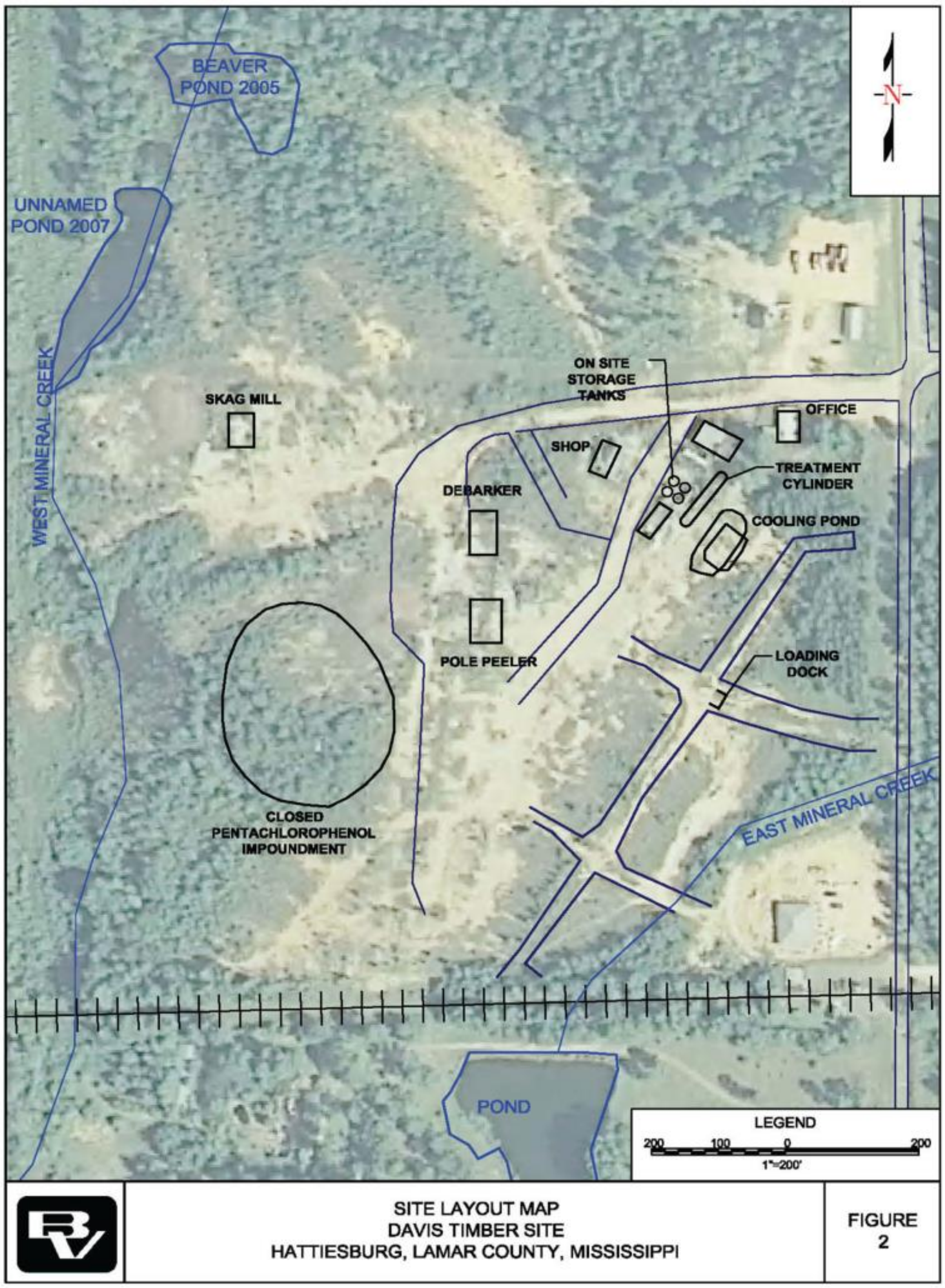


Figure 459. Davis Timber Superfund site layout map. Image 2171.

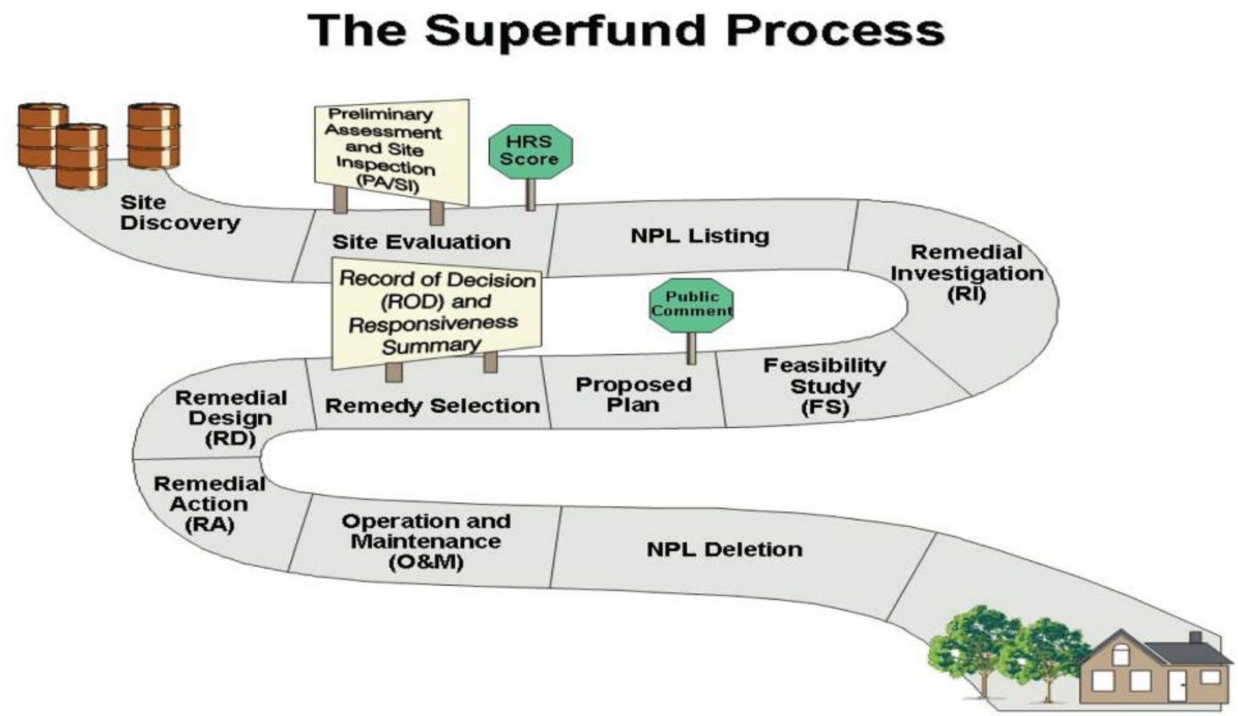


Figure 460. Steps through the Superfund process. Image 2172.

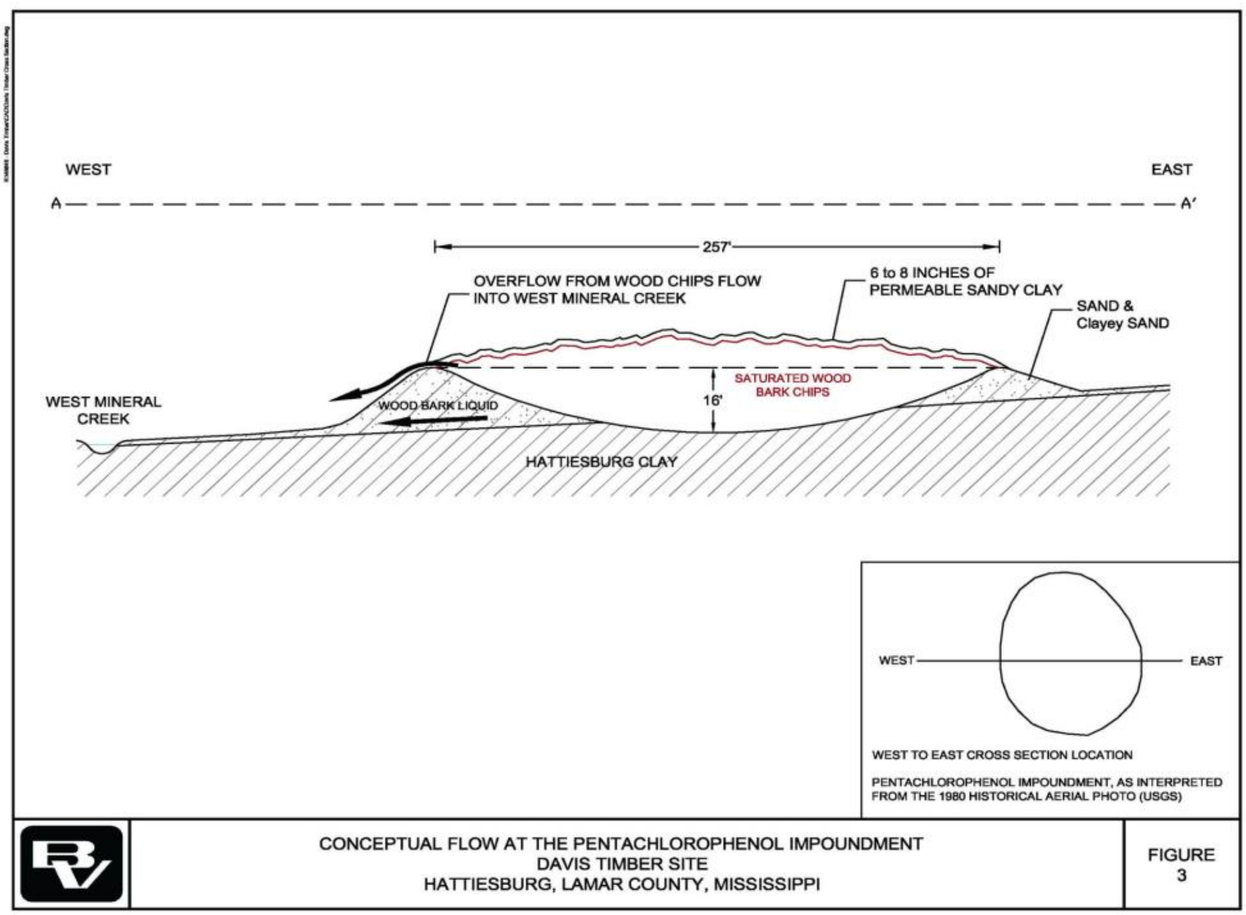


Figure 461. Leakage in the pentachlorophenol impoundment at the Davis Timber site. Image 2173.

terize onsite soils, creek and lake sediments, surface water, and groundwater. The RI report identified the nature and extent of contamination and determined the rate and direction contaminants might have traveled away from the source area. The report focused on locations, such as the impoundment, with the greatest potential as PCP source areas (**Figure 461**).

The Feasibility Study (FS) for the Davis Timber Superfund site was completed in April of 2009. This study used the RI results and site-specific data identified in the Baseline Human Health Risk Assessment (HHRA) for residential, industrial, and recreational receptors and the Step & Ecological Risk Assessment (ERA) to identify and screen remedial alternatives for the Site. The Site's anticipated future uses include commercial, recreational, and public land uses. Due to its proximity to the region's growing residential and commercial areas, the Site is wells suited for parks, community centers, walking trails, educational areas, sports fields, and wildlife habitat. Based on the likelihood that the Site would be used for recreational purposes rather than residential use, some contaminates were eliminated from the Contaminants of Concern (COCs), as they would not pose the same risk to a recreational user as they would a fulltime resident. The two COCs identified at the site were pentachlorophenol (PCP) and Dioxin Toxic Equivalents (TEQ), the later term referring to multiple dioxins and furans with varying human health and ecological effects. PCP, dioxin, and furan are a probable carcinogen to humans and pose an unacceptable risk to ecological receptors.

Site Geology. Surface soil at the site consists of a very thin layer of sandy clay overlying a very thick clay unit in the Hattiesburg Formation (**Figure 462**) that inhibits the vertical migration of precipitation. Thus, the majority of precipitation flows into local streams and not into the groundwater. Surface water runoff from the site flows into two intermittent tributaries of Mineral Creek: East Mineral Creek and West Mineral Creek. These tributaries flow northeast into Country Club Lake, a 66-acre recreational and fishing lake located 1.25 miles downstream of the site. Sediments from Beaver Pond (onsite) and West Mineral Creek were found to contain 120 to 1,800 parts per billion of PCP. Sediments in East Mineral Creek contained 14 to 8,200 parts per billion of PCP (**Figure 463**).

Figure 462. Ken Davis holding survey rod beside a fresh exposure of clay and sand beds in the Hattiesburg Formation in the type area at Hattiesburg, Mississippi, on the west side of Highway 49 just south of Interstate 59. Picture (digital; Image 931) was taken on May 10, 2007.

Contaminant of Concern	Potentially Impacted Receptor	Cleanup Level
Surface Soil		
Pentachlorophenol (PCP)	Ecological	13,000 µg/kg
Pentachlorophenol (PCP)	Human Health	23,800 µg/kg
Dioxin/Furan TEQ	Human Health	1 µg/kg (1,000 ng/kg) (Surface Soil)
Subsurface Soil		
Dioxin/Furan TEQ	Human Health	5 µg/kg (5,000 ng/kg)
Sediment		
Pentachlorophenol (PCP)	Ecological	7,600 µg/kg
Dioxin/Furan TEQ	Ecological	1.9 µg/kg (1,900 ng/kg)
Surface Water		
Dioxin/Furan TEQ	Human Health	$3x10^{-5}$ µg/L (0.00003 µg/L)

ERA=Ecological Risk Assessment TEQ = Toxic Equivalents
mg/kg = ppm µg/kg = ppb µg/L = ppb ng/L = ppt

Figure 463. Cleanup levels for contaminants of concern. Image 2174.

The information and figures given above, and the information in the following Remedial Action section, are from the *U.S. Environmental Protection Agency Superfund Proposed Plan, Davis Timber Superfund Site, Hattiesburg, Lamar County, Mississippi* (July, 2009). Pictures and addition information in the Remedial Action section are from Michael T. Slack, Assessment and Remediation II Branch Chief, Mississippi Office of Pollution Control.

Remedial Action. The Proposed Plan for the Site selected Site-Wide Alternative (SWA) SWA-3B that required the excavation of contaminated soils and sediments, which would be placed in an engineered impoundment onsite. Remedial Action for the Site was initiated in December of 2011, with an anticipated completion date of approximately 12 months. According to the EPA Superfund Proposed Plan, the preferred alternative consisted of the following actions:

1. Extract Impoundment liquid (estimated to be roughly 100,000 gallons and treat the liquid to remove the dissolved contamination; discharge the clean water back into West Mineral Creek (**Figure 464**).

2. Move a 500- to 1000-foot portion of West Mineral Creek (immediately adjacent to the Impoundment area) approximately 200 feet farther west of its current location (**Figure 465**).

3. Construct an earthen retaining wall or berm structure along the western boundary of the Impoundment between it and the newly relocated portion of West Mineral Creek.

4. Excavate and move contaminated soil (roughly 7,600 cubic yards) into the Impoundment area.

5. Dredge contaminated sediment from the creeks, ponds, and wetlands (roughly 3,600 cubic yards) and remove excess water and move into the Impoundment area.

6. Return the excavated and dredged material back to the Impoundment area.

7. Construct cap over Impoundment area (designed with a stabilizing sub-cap).

8. Back fill excavated and dredged locations with clean borrow material.

9. Implement land-use/deed restrictions to limit construction over the capped Impoundment and contaminated soil areas.

10. Grade and prepare the Site for better storm water drainage control

11. Establish and implement a long-term monitoring program to assess the effectiveness of the remedial action.

Figure 464. Treating contaminated water at the Impoundment area of the Davis Timber Superfund site in Lamar County, Mississippi. Picture (digital; Image 2175) was taken by Michael Slack on January 12, 2012.

Figure 465. Relocation of West Mineral Creek 200 feet west of its original location at the Davis Timber Superfund site in Lamar County, Mississippi. Picture (digital; Image 2176) was taken by Michael Slack on January 12, 2012.

Southeastern Wood Preserving Superfund Site

Site History and Location. The Southeastern Wood Preserving Site is a 25-acre property located in the northernmost part of the City of Canton, Mississippi. It was operated from 1928 to 1979 as a creosote wood preserving facility. Coal tar creosote and pentachlorophenol (PCP) were used as wood preservatives. The Site included three unlined wastewater treatment surface impoundments constructed for disposal of wood preserving treatment sludges and process wastewater. Before the 1977 Clean Water Act was enacted, the facility reportedly discharged approximately 50,000 gallons of wastewater directly into Batchelor Creek.

The Site has contaminated soil, sediment, and groundwater with creosote and creosote-related compounds. Ground water sampling at the Site identified 17 chemicals above EPA's Safe Drinking Water Act Maximum Contaminant Levels. Free-phase creosote was documented as entering Batchelor Creek along a 700-foot stretch with a down-stream impact of at least 4,500 feet. Batchelor Creek flows through a city park, a residential area, and downtown Canton before it enters Bear Creek. Residents use Batchelor Creek for fishing and recreational purposes.

Bottom sediment sludge from the three impoundments contained polynuclear aromatic hydrocarbons (PAHs) at levels of approximately 4,000 milligrams per kilogram (mg/kg) and was identified as a RCRA K001-listed hazardous waste. PAHs included acenaphthene at 705 mg/kg, naphthalene at 673 mg/kg, and benzo(a)pyrene at 224mg/kg. In 1986, EPA initiated an emergency response action at the site to stabilize the impoundments, which were overflowing at the time. The impoundments were dewatered and 8,000 cubic yards of bottom sludge was excavated and stabilized with approximately 70 cubic yards of cement kiln dust. The excavated material was stockpiled onsite for further treatment. The treatment facilities were constructed from January 1991 to mid-April 1991. Full-scale operation of the soil treatment system began in July 1991.

Constituent	Concentration (mg/kg)
Acenaphthene	705
Acenaphthylene	78.8
Anthracene	2.44
Benzo(a)anthracene	496
Benzo(b)fluoranthene/ Benzo(k)fluoranthene	513
Benzo(ghi)perylene	9.8
Benzo(a)pyrene	224
Chrysene	305
Dibenzo(ah)anthracene	27.05
Fluoranthene	419
Fluorene	32.2
Indeno(1,2,3-cd)pyrene	64.1
Naphthalene	673
Phenanthrene	266
Pyrene	ND (0.36)
Total PAHs	3,815

Figure 466. Concentrations of PAHs in excavated material from the Southeastern Wood Preservation Superfund Site. Image 2177.

Remedy Selection. The remedy selected for the Site was a slurry-phase bioremediation on the basis of cost. Also, this selection was preferable to land treatment as it could be done in a shorter time period and could achieve lower concentrations in the re-

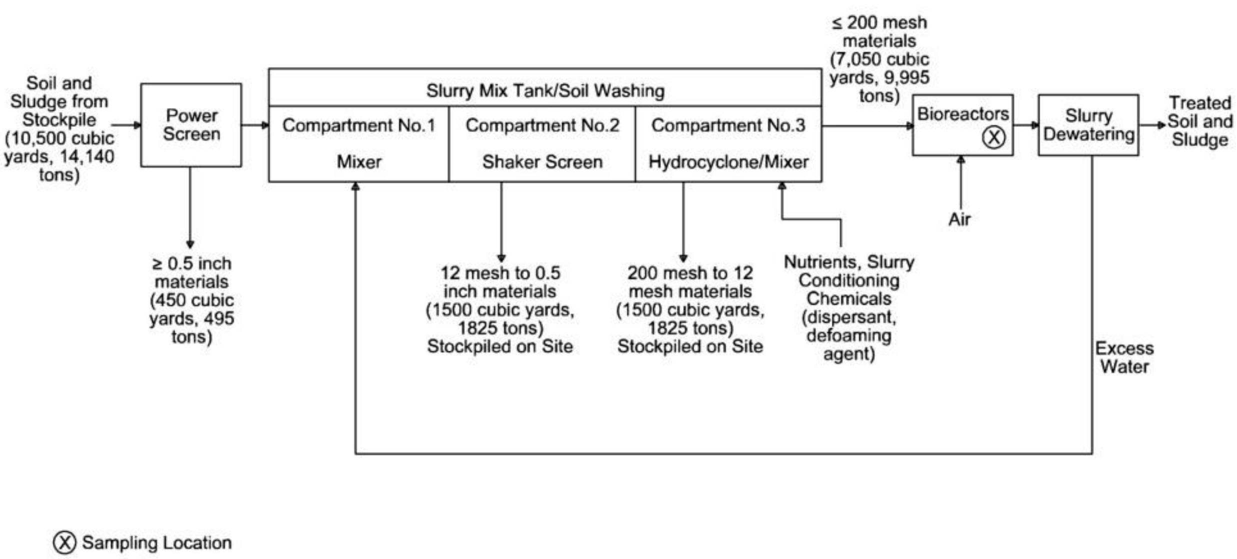


Figure 467 Three-compartment slurry mix tank system at the Southeastern Wood Preserving Superfund site. Image 2178.

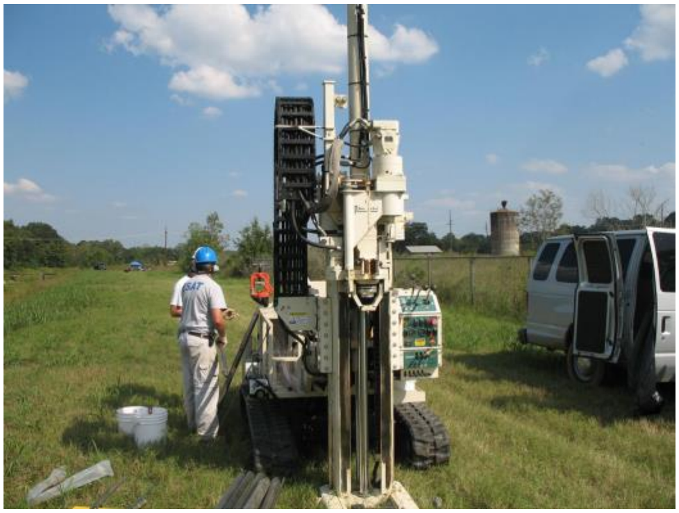


Figure 468. Direct push technology rig between the disposal cell at right and Batchelor Creek at left. Picture (digital; Image 2179) was taken by Richard Ball on September 18, 2007.

sidual soil. Cleanup goals of 950 mg/kg dry weight soil solids total PAHs and 180 mg/kg dry weight soil solids of B(a)P-equivalent PAHs were developed for the Site based on laboratory and field pilot test results and a site-specific health-based risk analysis. According to outcome data from 13 of the total 61 bioreactor batches, the average total PAH concentration was reduced from 8,545 to 634 mg/kg, which corresponded to a treatment efficiency of 93 percent. The efficiency for the B(a)P-equivalent concentration was a reduction from 467 to 152 mg/kg or 67 percent. **Figure 466** gives the concentrations of PAHs in the excavated material.

Contaminated soil and sludge excavated from the Site were processed through a slurry mix tank with three compartments (**Figure 467**). Compartment No. 1 added water to slurry the solids. Compartment No. 2 contained a shaker screen that removed debris between 12 mesh (0.0661 inches) and 0.5 inches. Approximately 1,500 cubic yards of debris were removed in this process. Compartment No. 3 removed some 1,500 cubic yards of sand-sized material between 200 mesh and 12 mesh. Also added in this compartment were nutrients and slurry conditioning chemicals (including a dispersant and defoaming agent). Sediments under the 200 mesh size were sent to the bioreactor for treatment and then dewatered and disked to dry. Processed debris and sand and treated soil and sludge were placed in a lined, capped disposal cell on site.

Cost. The approximate cost of this remedy upon completion was $2,900,000, with

Figure 469. Core with creosote-contaminated alluvium at top and Yazoo Clay at bottom. Picture (digital; Image 2180) was taken by Richard Ball on September 18, 2007.

$2,400,000 for activities directly related to treatment (mobilization /setup, startup/testing/ permits, and operation) and $500,000 for after-treatment activities (site restoration). This cost equated to $170 per ton ($230 per cubic yard) of soil and sludge treated (which totaled 14,140 tons or 10,500 cubic yards).

Coring in 2007. In 2007, an environmental drilling company was contracted to do

Figure 470. EPA and contract workers taking samples along Batchelor Creek. Picture (digital: Image 2181) was taken by Richard Ball on September 22, 2008.

Figure 471. Creosote oozing from fractures in the Yazoo Clay into the bottom of Batchelor Creek. Picture (digital; Image 2182) was taken by Richard Ball on September 8, 2009.

Figure 472. EPA Superfund sign at the Southeastern Wood Preserving remediation construction site. Picture (digital; Image 2183) was taken by Richard Ball on February 3, 2010.

Figure 473. Creosote draining from fractures in the alluvium and underlying Yazoo Clay on the banks of Batchelor Creek. Picture (digital; Image 2184) was taken by Richard Ball on October 20, 2009.

Figure 474. Layers of creosote in the alluvium of Batchelor Creek. Picture (digital; Image 2185) was taken by Richard Ball on October 20, 2009.

a series of core holes along the boundary between the disposal cell and Batchelor Creek. The concern was that creosote from the cell had leaked into the creek. Drilling (**Figure 468-469**) found no significant leakage from the disposal cell, indicating that creosote in the creek bottom and banks was the result of a long history of creosote contamination from the plant site. **Figure 470** shows an EPA worker and contract worker taking samples along Batchelor Creek in 2008. **Figure 471** shows creosote oozing from cracks in the Yazoo Clay into the bottom of Batchelor Creek. This picture was instrumental in obtaining EPA funding for an Emergency Response cleanup (**Figure 472**). Creosote can be seen

Figure 475. Excavating creosote contaminated soil from the bottom and banks of Batchelor Creek. Picture (digital; Image 2186) was taken by Richard Ball on October 1, 2009.

Figure 476. Hauling off contaminated sediments from Batchelor Creek to a disposal cell on site. Picture (digital; Image 2187) was taken by Richard Ball on October 1, 2009.

Figure 477. The deepest penetration of creosote into the Yazoo Clay and the deepest excavation of contaminated soil on Batchelor Creek. Picture (digital: Image 2188) was taken by Richard Ball on January 27, 2010.

Figure 478. Backfilling with clean soil at the deepest excavation of contaminated material on Batchelor Creek. Picture (digital; Image 2189) was taken by Richard Ball on January 27, 2010.

leaking from fractures in both the alluvium and Yazoo Clay along the banks of Batchelor Creek in **Figure 458**. **Figure 459** shows creosote in the alluvium of Batchelor Creek.

Emergency Response, Clean Water Act. In 2009 and 2010, a section of Batchelor Creek was excavated and rebuilt to remove free-phase creosote contamination. Creosote was found bleeding into the creek from fractured Yazoo Clay in the creek bottom and from alluvial sediments along the creek banks. In an Emergency Response provision of the Clean Water Act, funds were provided to excavate creosote-tainted materials from the creek and to build a slurry wall between the creek and the capped disposal cell on the site adjacent the creek. The cost of this action was on the order of $12 million.

The emergency response funds allowed a more immediate remediation, including:

1. Contracting an environmental drill company to core Batchelor Creek bottom to a depth of 5 to 20 to find the bottom of the polluted interval.

2. Damming up both ends of the polluted creek section and pumping creek water around the dammed section.

Figure 479. Grading the rebuilt bottom of Batchelor Creek. Picture (digital; Image 2190) was taken by Richard Ball on January 27, 2010.

Figure 480. Claw bucket used to dredge the slurry wall between the disposal cell and Bachelor Creek. Picture (digital; Image 2191) was taken by Richard Ball on February 3, 2010.

Figure 481. Holding tanks for cement and bentonite to be mixed in equal amounts in a slurry for the slurry wall. Picture (digital; Image 2192) was taken by Richard Ball on February 18, 2010.

Figure 482. Pumping the slurry mix into the slurry wall trench. The mix is pumped in as the trench is being excavated, thus protecting the trench walls from caving in. Picture (digital; Image 2193) was taken by Richard Ball on February 18, 2010.

3. Removing riprap and excavating the creek bottom and sides to clean uncontaminated clay and backfilling with fill dirt/sand. The excavated began at the west end (the most polluted end) and continued to the east end of the dammed section (**figures 481-482**).

4. Constructing a slurry wall between the creek and the disposal cell adjacent the creek, while riprap was replaced on the creek sides and bottom (**figures 466-467**)

Superfund Site Selection. On March 13, 2012, EPA added Southeastern Wood Preserving as one of "four new hazardous waste sites in the Southeast that pose risks to human health and the environment to the National Priorities List (NPL) of Superfund sites." EPA added a total of nine sites nationally on that date and explained the Superfund program in this way: "Superfund is the federal program that investigates and cleans up the most complex, uncontrolled or abandoned hazardous waste sites in the country." The tally of Superfund sites since 1983 totaled 1,661 sites, 359 of which had been cleaned up leaving 1,302 sites currently on the list (included the nine new sites).

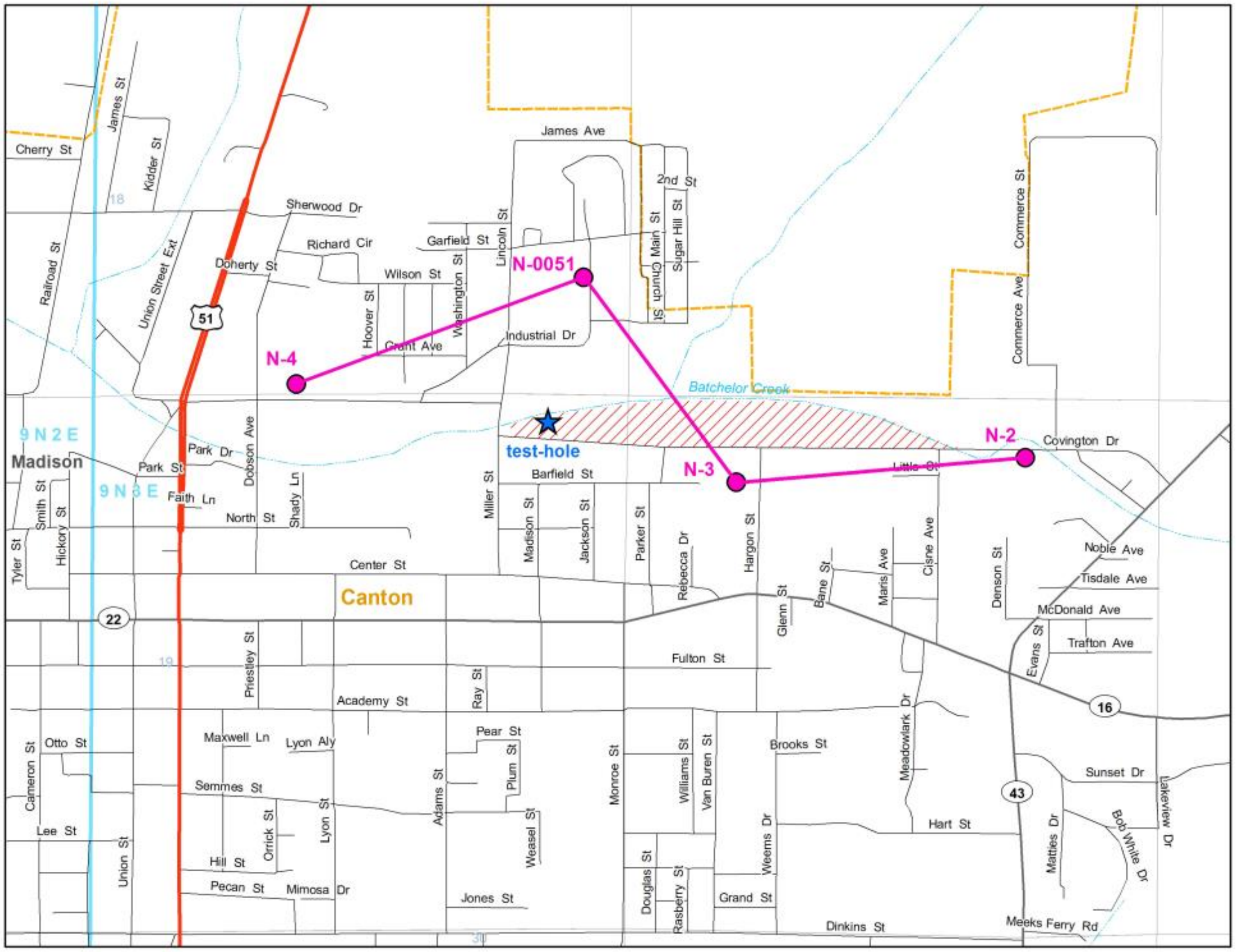


Figure 483. Location map of the Southeaster Wood Preserving Superfund site (shaded area), cross section, and test hole, from *Environmental News*, January 2013, p. 21.

In 2011, the Southeastern Wood Preserving site was added to EPA's Nation Priorities List as a Superfund site. A new series of soil testing and coring activities were begun in November of 2012 with the objective of testing subsurface strata and groundwater for contamination. The first of these drill tests was conducted from November 6-7, 2012, by a Geoprobe rotary sonic drilling rig and found creosote contamination in fill dirt at 10-15 feet below ground level. The drill test then encountered Yazoo Clay at 15-40 feet, Moodys Branch Formation at 40-70 feet, and the upper clay of the Cockfield Formation at 70 feet to the bottom of the hole at 170 feet. Additional drill tests will sample strata for contamination and test the first aquifer sands for possible groundwater contamination. The Office of Geology had an interest in cores from this site as they included the contact between the Moodys Branch Formation and underlying Cockfield Formation. This contact is also the boundary between the Jackson and Claiborne groups and represents a time 38 million years when a worldwide rise in sea level flooded organic-rich delta clays of the Cockfield Formation and deposited the overlying fossiliferous marine sands of the Moodys Branch Formation. To help with the coring project, the office correlated the geophysical logs of four of the City of Canton's water wells, which line up from west to east along Batchelor Creek (**figures 483-484**). These logs show the location of aquifer sands in both the Cockfield and underlying Kosciusko formations in the same area in which coring was be done (**figures 485, 489**). The stratigraphic sequence here, in ascending order, consists of: (1) alluvium, (2) Yazoo Clay, (3) Moodys Branch Formation, (4) Cockfield Formation (**figures 486-489**), (5) Cook Mountain Formation, (6) Kosciusko Formation, and (7) Zilpha Clay. Aquifer sands in both the Cockfield and Kosciusko formations are better developed toward the east within the cross section, while an upper Cockfield sand is developed in the two western wells.

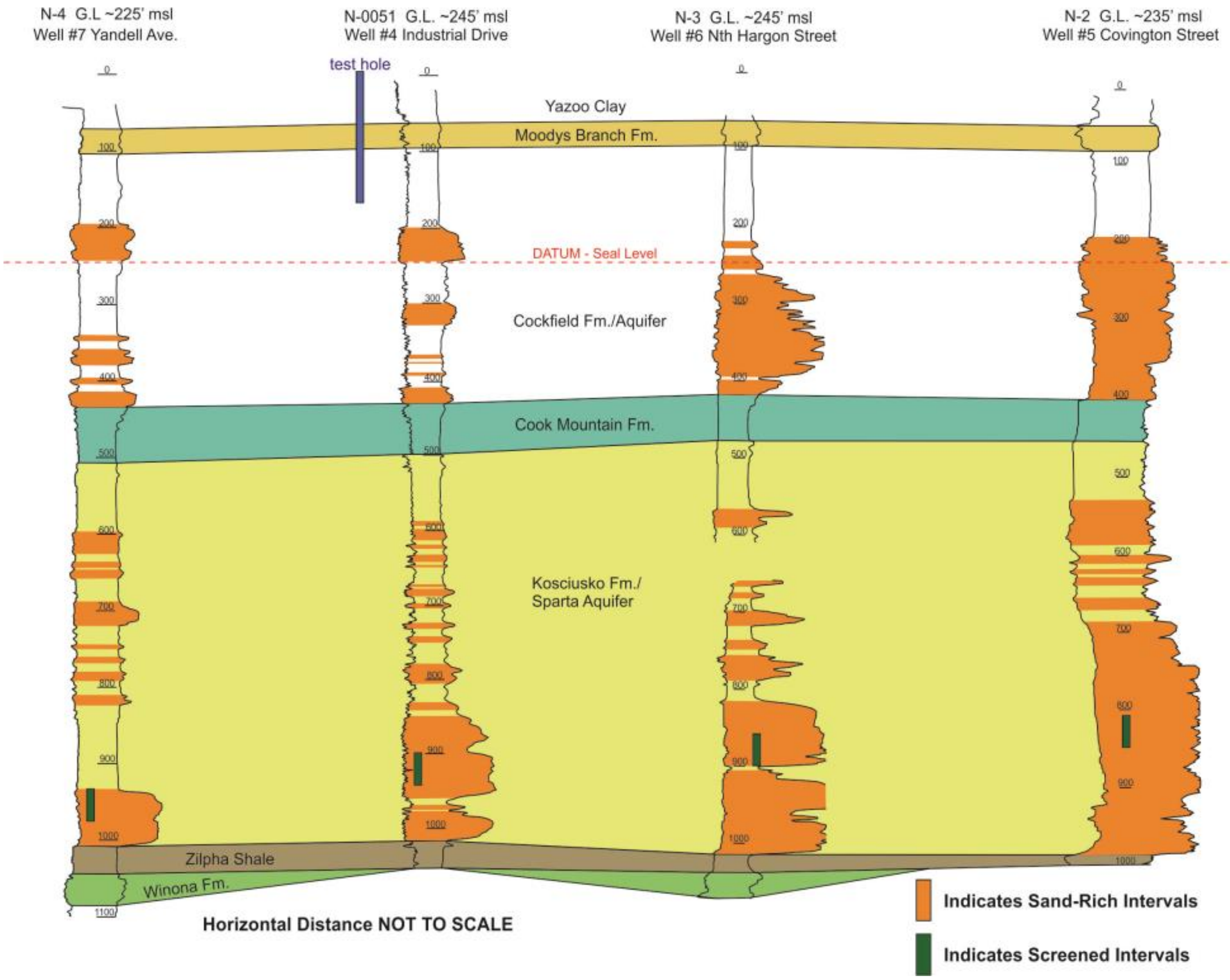


Figure 484. Structural cross section through four City of Canton water wells, showing sea-level datum, formations, aquifer sands, and screened intervals for water wells. Well N-3 is not in use and is slated to be sealed with grout. The Geoprobe rotary sonic test hole is projected due north to the line of section. Figure from *Environmental News*, January 2013, p. 21.

Figure 485. Full view of the small Geoprobe rotary sonic drilling rig at left and core retrieval at right, during drilling on the first core hole at the Southeastern Wood Preserving Superfund site at Canton, Mississippi. Pictures were taken on November 7, 2012.

Figure 486. Geologists from Black & Veatch Special Projects Corp. examine a five-foot core of dark-brown clay from the upper Cockfield Formation from a depth of 115-120 feet below ground level. Pictures were taken on November 7, 2012.

Figure 487. Moodys Branch Formation from 60-70 feet at right, and Cockfield Formation from 70-80 feet at right at the Southeastern Wood Preserving Superfund site in Canton, Mississippi. Pictures were taken on November 7, 2012.

Figure 488. Fossil leaf in the Cockfield Formation at the Southeastern Wood Preserving Superfund site core. Picture was taken on November 7, 2012.

Figure 489. At top: Large rotary sonic rig drilling the second core at the Southeastern Wood Preserving Superfund site in Canton, Mississippi. At bottom: Ten-foot core intervals from left to right: 30-40 feet, 40-50 feet, 50-60 feet, 60-70 feet, 70-80 feet and 80-90 feet. The top of the unweathered Yazoo Clay is at 34 feet, the top of the Moodys Branch Formation is at 57.3 feet, and the top of the Cockfield Formation is at 81.9 feet. Pictures were taken on January 8, 2013.

Picayune Wood Treating Superfund Site, Picayune, Pearl River County, Mississippi

The Picayne Wood Treating Superfund site is a 30-acre site located at 403 Davis Road in Picayune, Mississippi (**figures 490-492**. It was added to the National Priorities List in 2004 based contamination in both soil and groundwater. Some 220,000 cubic yards of contaminated soils and sediments were excavated and placed in disposal cells onsite. Remediation for groundwater contamination consisted of a combination of containment and treatment. A 70-foot-deep slurry wall was construction around the site to contain a plume of contaminants. Groundwater contaminants outside the contained areas were treated by a combination of in situ flushing, chemical oxidation, and enhanced bioremediation.

History. The plant was constructed around 1945 by Crosby Forest Products, Inc., to produce treated wood, consisting primarily of utility poles and foundation pilings. It was bought by Crosby Wood Preserving, Inc., in 1963 and later by Wood Treating, Inc. (WTI), in 1973. Operations ceased in 1999. Coal tar creosote and PCP in a petroleum carrier were the chemicals used in the wood treatment process until 1982 after which only creosote was used. Waste waters and sludge from the treatment process were contained in two unlined surface impoundments, the oldest was constructed in 1946 to contain cooling water and condensable organic vapors. In 1975, the northern-most trench impoundment was constructed for the wastewater treatment system. Between 1975 and 1980, two additional trench impoundments were dug; no wastes were added to these after 1980. Cooling water pond and trench impoundments were closed after groundwater contaminants were discovered beneath two closed impoundments in 1985. The closure consisted of the removal of all pumpable sludges, solidification of the remaining sludges, a capping with a “very impermeable” cap.

In October of 1991, WTI in-

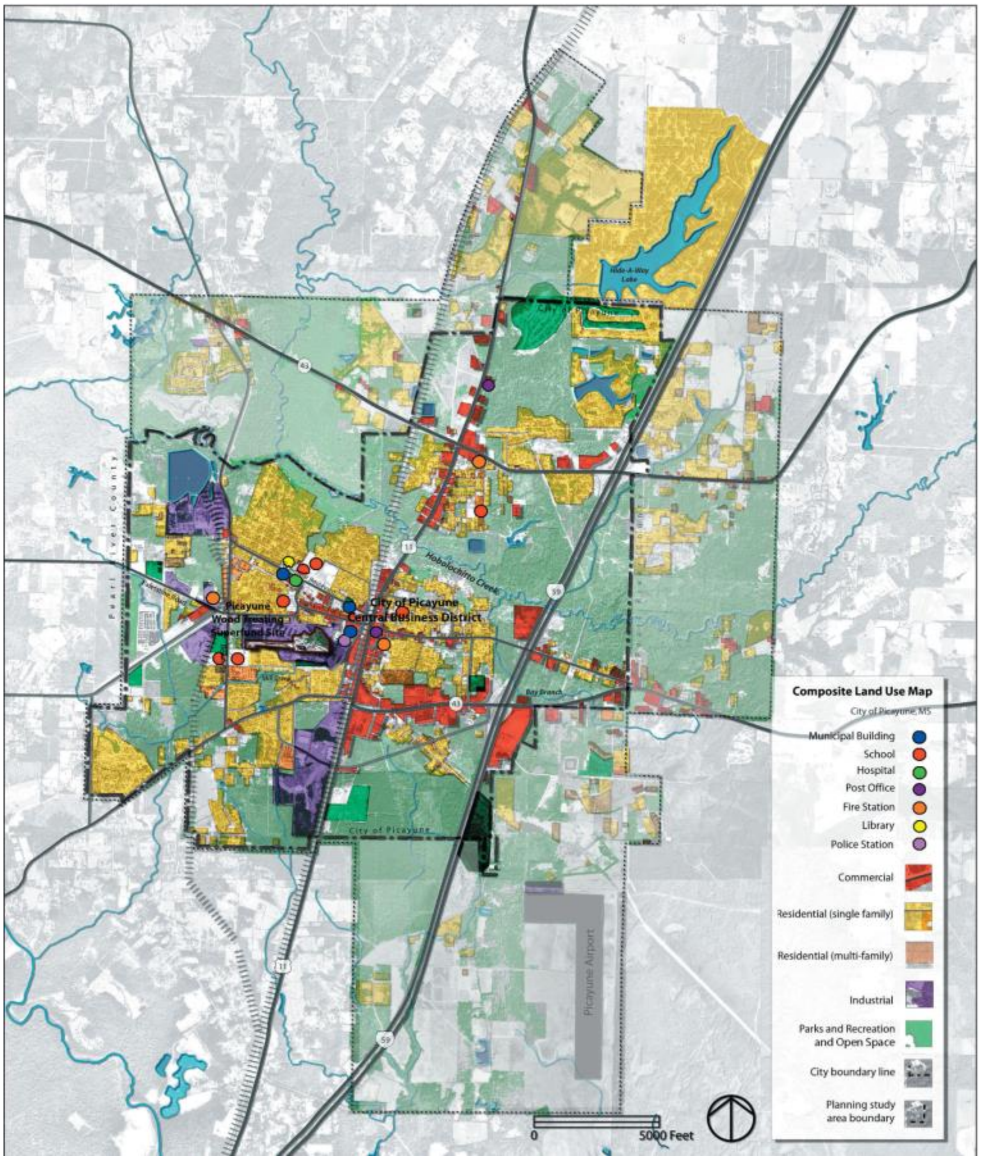


Figure 490. The City of Picayune composite zoning map. The Picayune Wood Treating Superfund site is close to Picayune’s Central Business District (Picayune Land Use Committee, 2005). Image 2291.

stalled six recovery wells for a groundwater pump and treatment system. The system was operated for a period and then dismantled. In an emergency response action from October 1999 to 2001, EPA removed all tanks, vats, and ditches were waste products leaked or had potential to leak. Liquid waste was removed or treated on site. Some 175 cubic yards of asbestos was also removed and disposed of in the Central Landfill in McNeil, Mississippi.

Figure 491. Site Surroundings Map. The Picayune Wood Treating Superfund site is surrounded by residential neighborhoods to the north and south. The Picayune's Police Headquarters is the blue square at right. Close by are Southside Elementary and Westside Elementary schools and the city's middle and high schools (Picayune Land Use Committee, 2005). Image 2292.

Site Geology. The site is about three miles east of the Pearl River on a generally flat surface with an average elevation of 59 feet and a vertical relief on site of less than seven feet. Surface soils in the upper foot at the site consist of soft, highly plastic clays; sandy clays; and fine-grained clayey sands. These interbedded clays, silts, and sands continues to a depth of 35 to 45 feet below the surface and comprises a sedimentary unit identified as the Pamlico Sand in an EPA *Record of Decision* report dated September 2007. The report followed the coastal geology map of Brown (1944) (**Figure 493**). Between 35 to 45 feet and 70 to 75 feet is a section of gravely sands that Brown (1944) and the EPA report 2007) placed in the Citronelle Formation. Here this section is placed as a coarse-grained interval of the upper Graham Ferry Formation. Below 70 to 75 feet is a "very distinct, highly plastic green clay" in the Graham Ferry Formation. This clay was reported to have a lateral continuity across the level plain between Hobolochitto Creek and the Pearl River. Eleven borings penetrated it from 2 to 20 feet with no change in lithology. Rollins (1987) reported that logs of deep water wells in the immediate vicinity indicated the

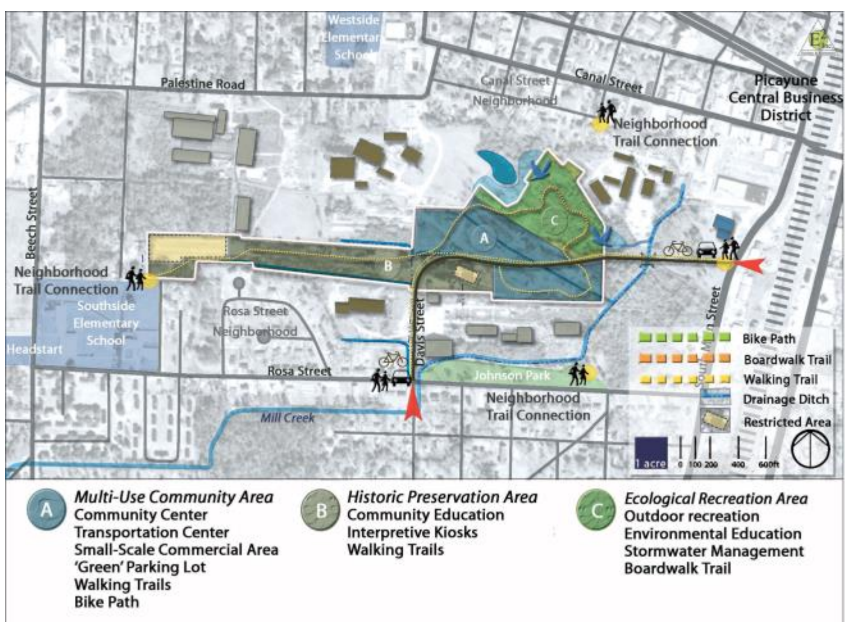


Figure 492. Future Use Map for the Picayune Wood Treating Superfund site, including a Multi-Use Community Area, Historic Preservation Area, and Ecological Recreation Area, complete with bike path, boardwalk trail, and walking trail (Picayune Land Use Committee, 2005). Image 2293.

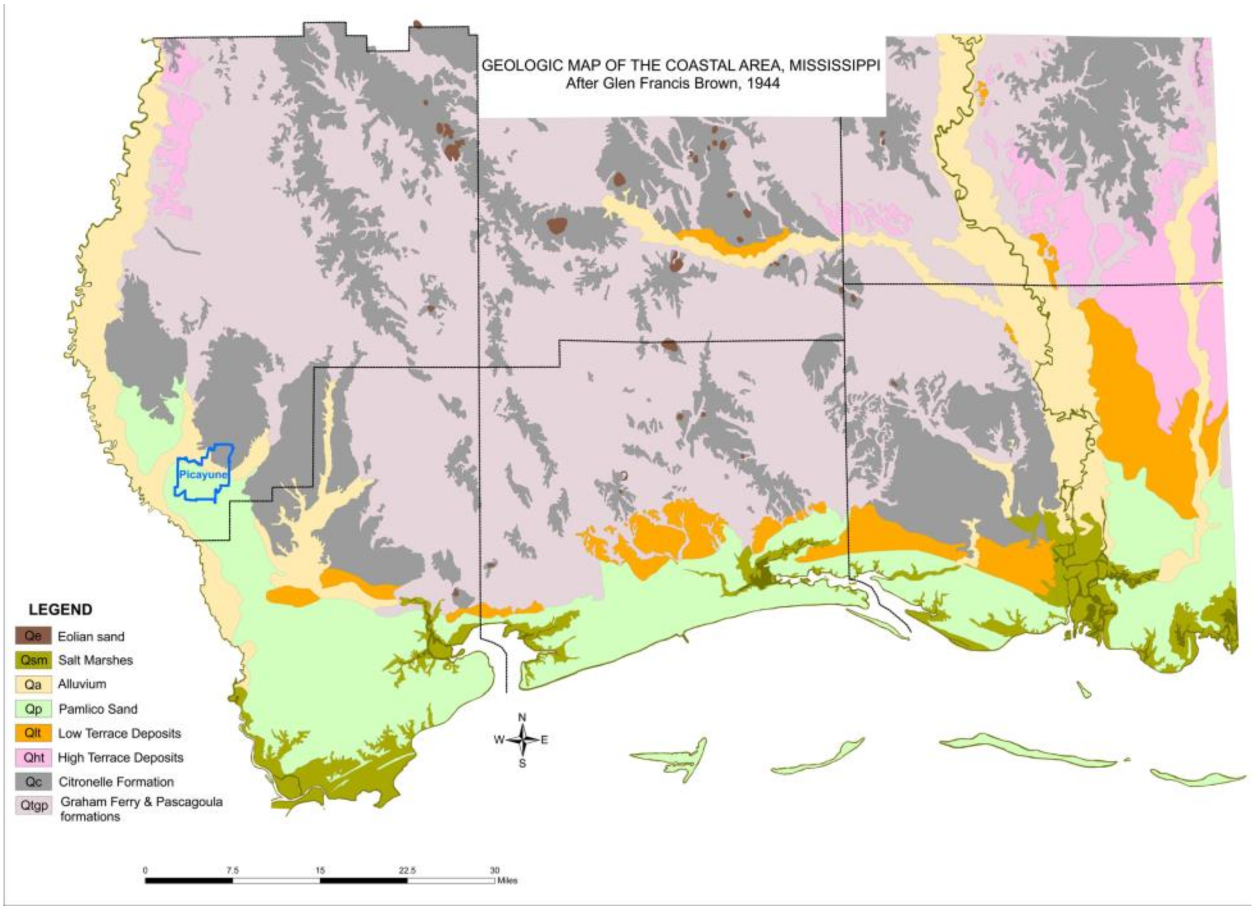


Figure 493. Location of the City of Picayune on the Geologic Map of the Coastal Area, Mississippi after Brown (1944). Image 2294.

clay stratum to have thicknesses of 100 to 300 feet.

Site Hydrogeology. Collectively, the "Pamlico Sand" and the coarse-grained "gravely sand" of the upper Graham Ferry Formation comprise a "semi-unconfined" surficial aquifer. The water table occurs 20 to 25 feet below the surface across the site; the general direction of groundwater flow is to the west with a slight downward vertical gradient. This surficial aquifer is not currently used as a drinking water source in the site vicinity. The City of Picayune drinking water wells are completed to 1,042 feet or greater in the Graham Ferry aquifer, below the confining clay at 70 feet. City of Picayune wells 1, 2, and 3 are located within 0.25 to 0.5 miles east of the site (**Figure 494**). There are no known private wells within one mile of the site.

The final phase of remediation at the Picayune Wood Treating site began in February of 2012 (Pittari, 2012a). Two cells were created to hold about 100,000 cubic yards of contaminated soil on-site. The surficial aquifer beneath the cells was confined by the construction of a three-foot-wide and 70-foot-deep slurry wall comprised of a soil-bentonite mix (Pittari, 2012b). **Figures 495-500** show the construction of the slurry wall for the west cell at the Picayune Wood Treating site.

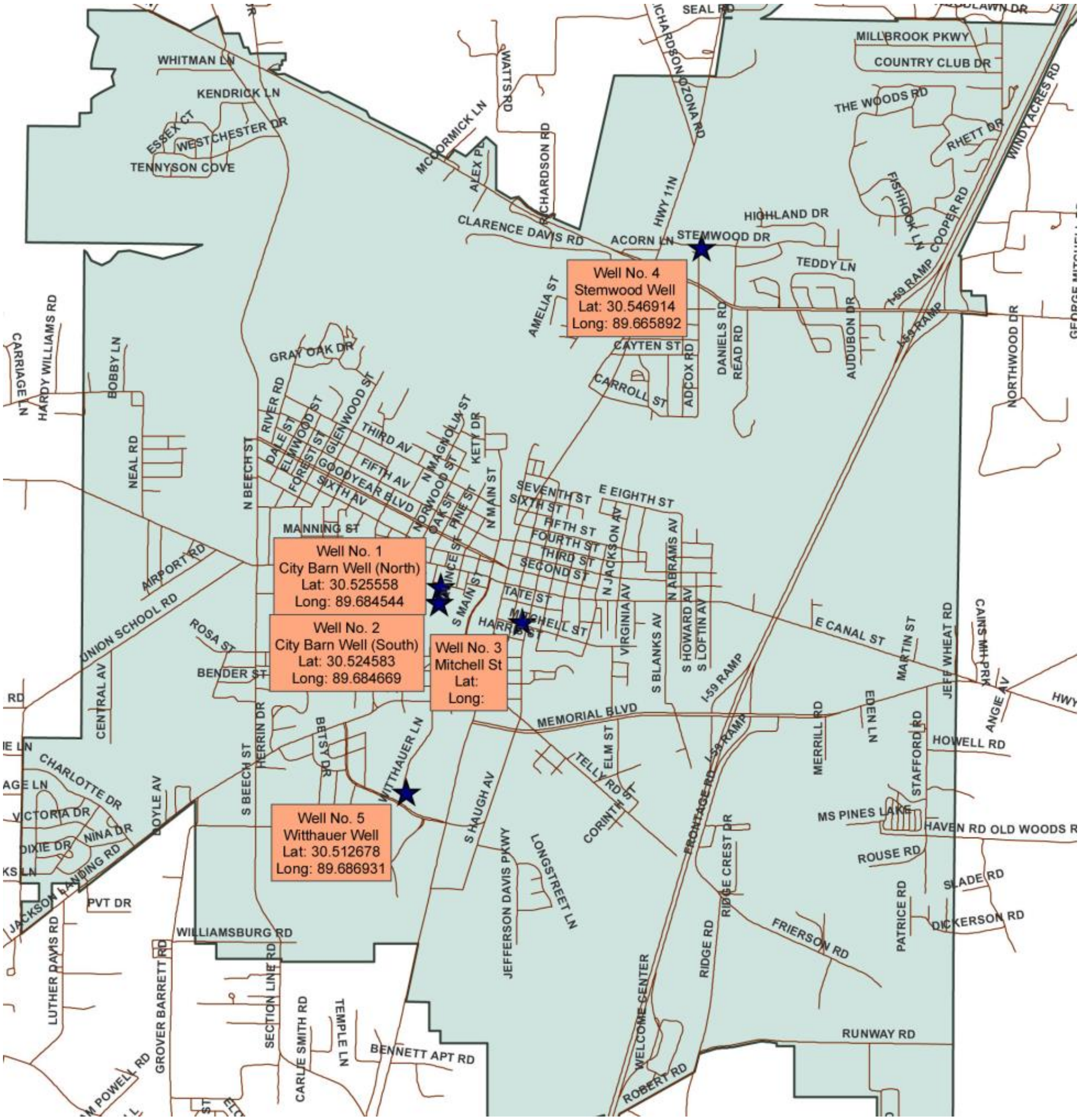


Figure 494. Location map of the City of Picayune water wells (from Vernon Moore, Dungan Engineering). Image 2295.

Figure 495. West cell long stick excavator at the Picayune Wood Treating Superfund site. Picture was taken by Michael Taylor in 2012. Image 2296.

Figure 496. Slurry clay mixing pond at the Picayune Wood Treating Superfund site. Picture was taken by Michael Taylor in 2012. Image 2297.

Figure 497. West cell pre-trenching activity at the Picayune Wood Treating Superfund site. Picture was taken by Michael Taylor in 2012. Image 2298.

Figure 498. West cell slurry mix at the Picayune Wood Treating Superfund site. Picture was taken by Michael Taylor in 2012. Image 2299.

Figure 499. West cell slurry wall trenching at the Picayne Wood Treating Superfund site. Picture was taken by Michael Taylor in 2012. Image 2300.

Figure 500. Long stick excavator excavating the west cell slurry wall at the Picayune Wood Treating Superfund site. Picture was taken by Michael Taylor in 2012. Image 2301.

Uncontrolled Site Voluntary Evaluation Program

The Uncontrolled Site Evaluation Trust Fund was passed by the Mississippi Legislature and signed into law by the governor in 1996 as Section 17-17-54 of Mississippi Code. This fund established the Uncontrolled Site Voluntary Evaluation Program, which enables accepted parties to participate in a program that will expedite the evaluation of site information. An uncontrolled site is defined as "a site, facility, plant, or location where hazardous or toxic wastes have been released into the environment and there is no federal environmental program which can handle the problem." More than 1,500 such sites are on record at the MDEQ, and 3 or 4 sites are added to the list each month. Many of these sites have been placed on the "back burner" due to staff and budget limitations. Uncontrolled Sites are prioritized by MDEQ staff according to: (1) Actual or potential threat to the public health, (2) Actual or potential threat to the environment, (3) Whether the site is currently being considered for economic development, and (4) Whether the site is currently participating in the Uncontrolled Site Voluntary Evaluation Program.

By participating in the Voluntary Evaluation Program, a property owner or accepted party can get their site off the "back burner" and move it forward in the evaluation process. They also agree to pay fees to cover the cost of the process. Motivations for moving a site forward may include plans to develop or sell the property or to avoid liability as the party responsible for the pollution.

ARAMARK Dry Cleaning Site in Jackson, Mississippi

An example of a site in the Uncontrolled Site Voluntary Evaluation Program is the old ARAMARK dry cleaning operation at 421 W. Woodrow Wilson Boulevard (at Five Points) in Jackson, Mississippi (**figures 501-502**). In this case, the Pear Family wanted their former tenant ARAMARK to clean up pollution on their property created by ARAMARK's dry cleaning business.

Site History. The main part of the ARAMARK facility at 421 W. Woodrow Wilson Boulevard, was constructed by or before 1937 at a time when most of the surrounding land

Figure 501. Location of the Aramark dry cleaning facility in Jackson, Mississippi (Vapor Intrusion Investigation Work Plan, EME Environmental Solutions, July 13, 2010, Figure 1)..

was undeveloped. Since the 1940's, the facility was operated as a commercial laundry by numerous companies under various names. The property was purchased in the mid 1950's by the Pear Family and was leased to Independent Linen, an industrial laundry, between the early 1950's and through the late 1960's. All-State Linen leased the property from the Pear Family from November 1969 to February 1975, when Southern Quality Service Corp. accepted the lease. Through a merger, Southern Quality became Means Services, which was later acquired by ARAMARK. ARAMARK remained on the property till the mid-1980's.

In approximately July of 1976, a perchloroethylene (PCE) dry operation was initiated at the site, which included: (1) an exterior PCE storage tank, (2) a 250-gallon capacity, dual-phase PCE washer, (3) interior PCE storage tanks, (4) a PCE still, and (5) a sludge cooker. PCE dry cleaning was conducted from 1976 to 1983 or 1984. White Rose, Inc. (White Rose) leased the facility on May 21, 1985, as a commercial water-wash laundry. In March 1995, White Rose was purchased by American Linen Supply Company, which changed its name in 1998 to AmeriPride Linen and Apparel Services, Inc. (AmeriPride). AmeriPride was the last tenant that operated a laundry and left the site on October 31, 2004. ARAMARK purchased the property from the Pear Family Trust in late 2010 "specifically to undertake any future environmental activities needed to respond to subsurface contamination from the former dry cleaning operation." Environmental activities at the site are being managed and conducted by ARAMARK.

In the 1980s total petroleum hydrocarbons (TPH) were found to be high at the facility. A remediation of the TPH problem was done in April of 1992 by the removal of an underground gasoline storage tank from the property. PCE pollution at the facility was discovered in 1994 before the sale of White Rose to American Linen Supply. The facility had a record of environmental issues and the buyer wanted additional environmental testing. A trench was dug around the perimeter of the facility and uncovered PCE in the soil.

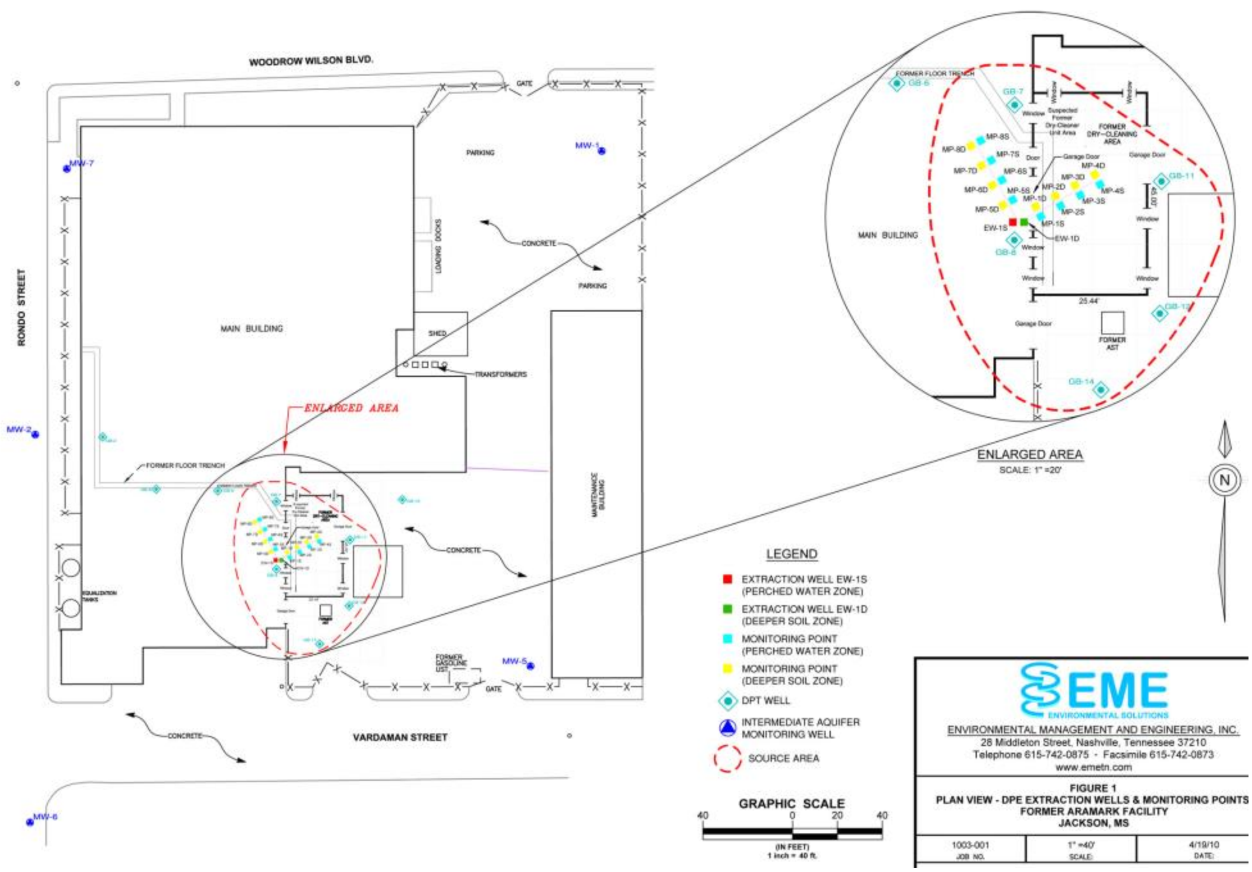


Figure 502. Location of test well at the Aramark dry-cleaning facility on West Woodrow Wilson Boulevard in Jackson, Mississippi (Work Plan for Source Area Remediation, EME Enviornmental Solutions, July 13, 2010, Figure 1).

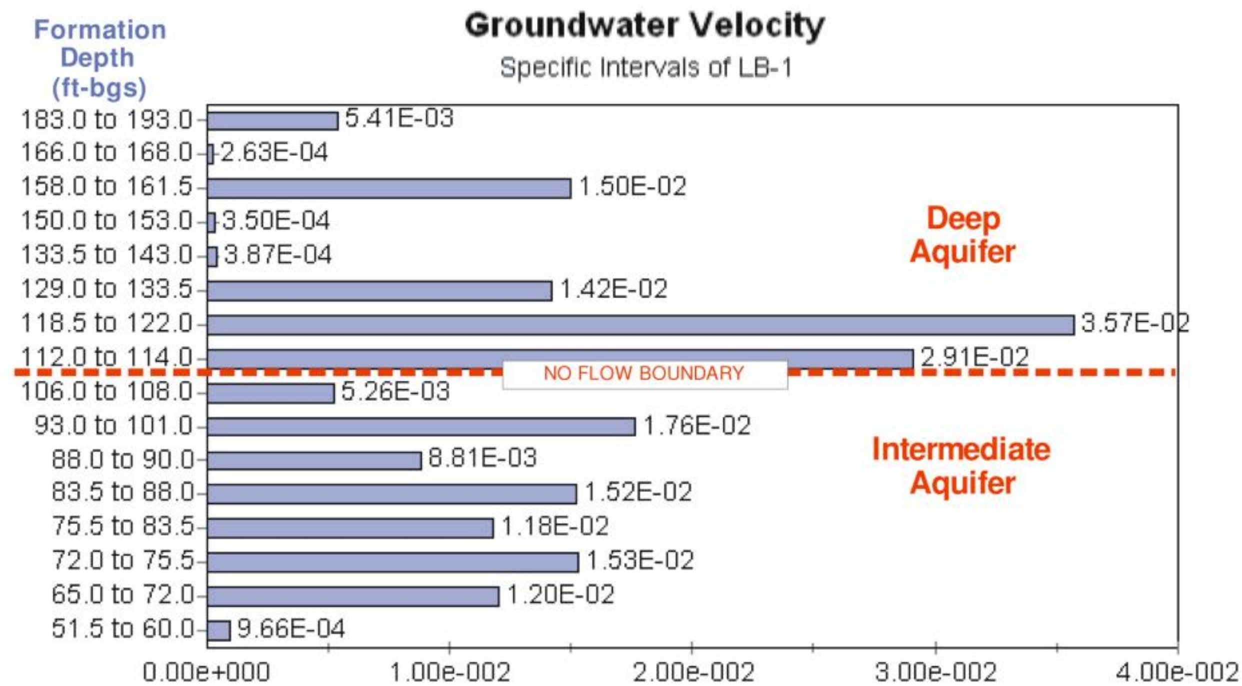


Figure 503. Groundwater velocity in the Deep and Intermediate aquifers at the ARAMARK dry-cleaning site in Jackson, Mississippi (Delineation of Facility-Associated Contaminants, EME Environmental Solutions, July 13, 2010, p. 10.

Perchloroethylene. Perchloroethylene (PCE or PERC) is the industrial name for tetrachloroethylene, also known as dry-cleaning fluid, a colorless liquid used in dry cleaning of fabrics. It has a sweet odor that came be detected by most people at 1 part per million. PCE is volatile, highly stable, nonflammable, and an excellent solvent for organic materials. Other uses for this compound include use as a degreaser for metal parts in the automotive and metalworking industries, as a paint stripper and spot remover, and at one time was used in the manufacture of HFC-134a and related refrigerants. PCE can enter the body through respiratory or dermal exposure and is classified as a Group 2A carcinogen, which means that it is probably carcinogenic to humans. It has also been tied by a "lot of circumstantial evidence" to a nine-fold increase in the risk of developing Parkinson's disease.

Because of its volatility, 90% of PCE produced is released into the air and 10% to water. In water it is present as a dense non-aqueous phase liquid that is toxic at low levels and, with a specific gravity of 1.62, is dense enough to sink below the water table, complicating cleanup activities. PCE degrades into trichloroethylene, which is also a carcinogen and has a specific gravity of 1.466.

Site Geology. The site is high on the Jackson Dome and is underlain in descending order by: (1) about 20 feet of alluvium, (2) about 30 feet of Yazoo Clay, (3) about 10 feet of the sandy Moodys Branch Formation, and (4), at a depth of 70 feet, where a sample is descrbed as "very thinly bedded," the silty to sandy upper Cockfield Formation. A perched water zone was encountered in well borings from 0 to 12 feet below ground surface in the alluvium. The zone consisted of tight blocky clay and had no substantive groundwater flow. The perched water zone directly beneath the former dry cleaning operations room and the southern portion of the main plant is highly impacted with PCE and is considered the "source area" to be remediated in ARAMARK's April 19, 2010 remediation work plan.

Water-bearing sands in the Moodys Branch Formation and the upper Cockfield Formation from 51.5 to 108 feet below ground surface are grouped together in a unit named the "Intermediate Aquifer" (**Figure 503**). This aquifer underlies the entire study area and is the first and primary water bearing unit in which contaminants might migrate offsite. The static water table in this aquifer ranges from 40 to 47 feet below ground surface, with the main component of flow to the northwest. The In-

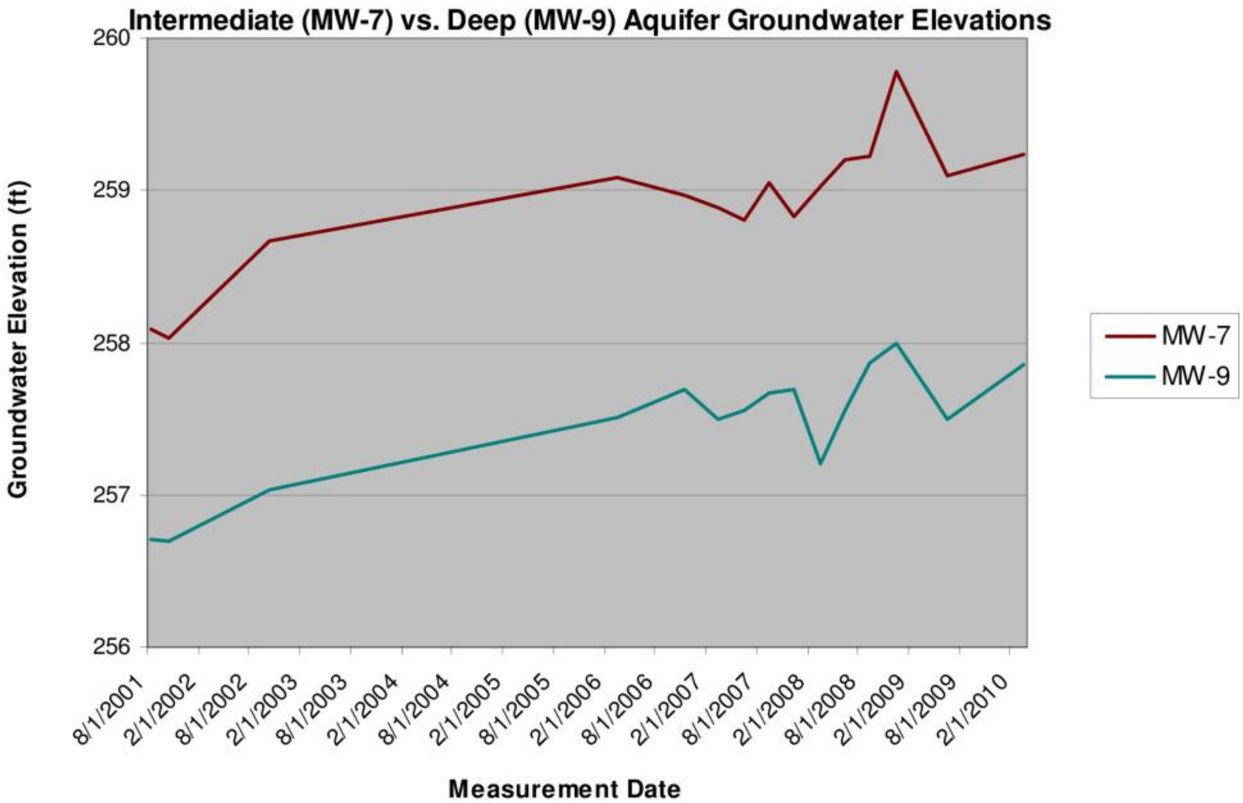


Figure 504. Water level correlations between the Intermediate and Deep aquifers at the ARAMARK dry -cleaning site in Jackson, Mississippi (Delineation of Facility-Associated Contaminants, EME Environmental Solution, July 13, 2010, p. 8.

termediate Aquifer contains a plume of PCE contamination in the Moodys Branch Formation (near the source area in well MW-2, screen interval at 47-57 feet below ground level) produced by the migration of PCE fluids through the Yazoo Clay from the overlying perched water zone. In a July 13, 2010, report, this plume was described as "defined, is relatively stable and the overall contaminant levels are declining."

A unit recognized as the "Deep Aquifer" includes a sandy interval in the Middle Cockfield Formation, possibly equivalent to the upper Cockfield aquifer of regional extent, which occurs below a clay layer at approximately 109 feet below ground surface and dips to the southwest at about 1.3%. This aquifer was found at depths of 112 to 193 feet below surface level, with sands at 112 to122 feet exhibiting the greatest groundwater velocity. Tests indicate that the hydrology of the Deep Aquifer is not directly connected to the Intermediate Aquifer and that the clay at 109 feet below ground surface is a confining unit between these aquifers (**Figure 504**).

Site Remediation. In ARAMARK's July 13, 2010, work plan, the company proposed to use "dual-phase vapor extraction (DPVE) as the in-situ remediation technology to remove PCE-associated contamination, both horizontally and vertically, form the Source Area." This process places a vacuum on "the subsurface media that is sufficient enough to move or pull both air and water from the subsurface and treated, if necessary, before disposal." The DPVE system would be connected to paired extraction wells in the perched water zone of the source area, one screened in the upper 20 feet and the other screened from 25 to 35 feet below ground surface.

The ARAMARK report stated that PCE -associated contamination in the Intermediate Aquifer indicated that "the Source Area contamination extends to depths prohibiting their physical removal through excavation or other means." The plan for the Intermediate Aquifer was to continue its program (initiated in 2006) to monitor and define the PCE plume in the Intermediate Aquifer as part of a "monitored natural attenuation (MNA) remedy."

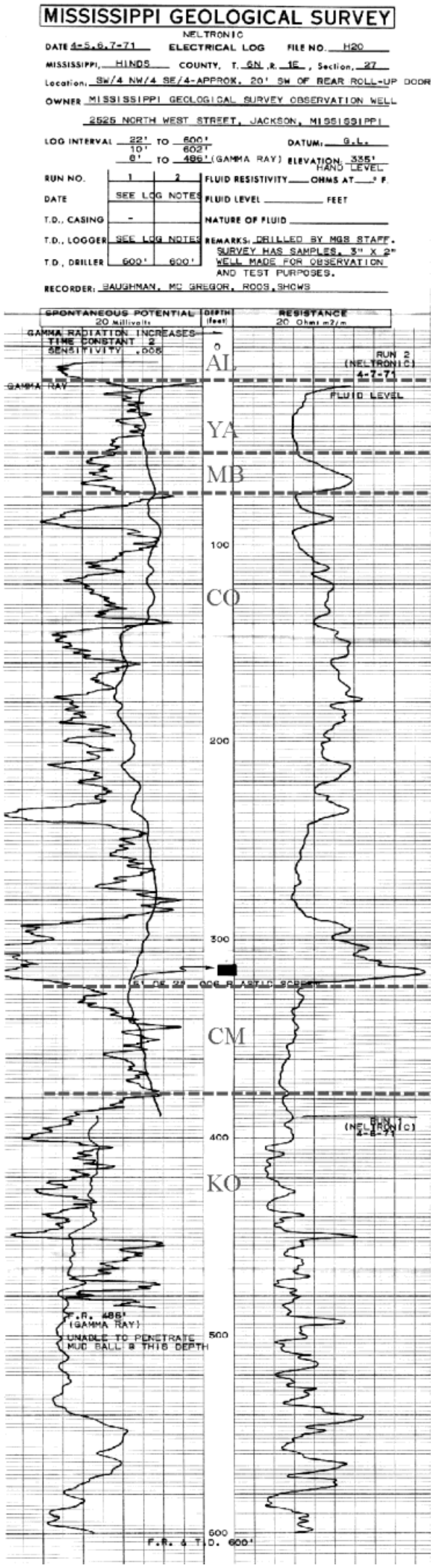


Figure 505 (left). The geophysical log at left for a groundwater-level monitoring well at 2525 Northwest Street in Jackson, Mississippi; AL = alluvium, YA = Yazoo Clay, MB = Moodys Branch Formation, CO = Cockfield Formation, CM = Cook Mountain Formation, and KO = Kosiusko Formation . The screen is set in the middle of the log between 310 and 320 feet in the basal sand of the Cockfield Formation.

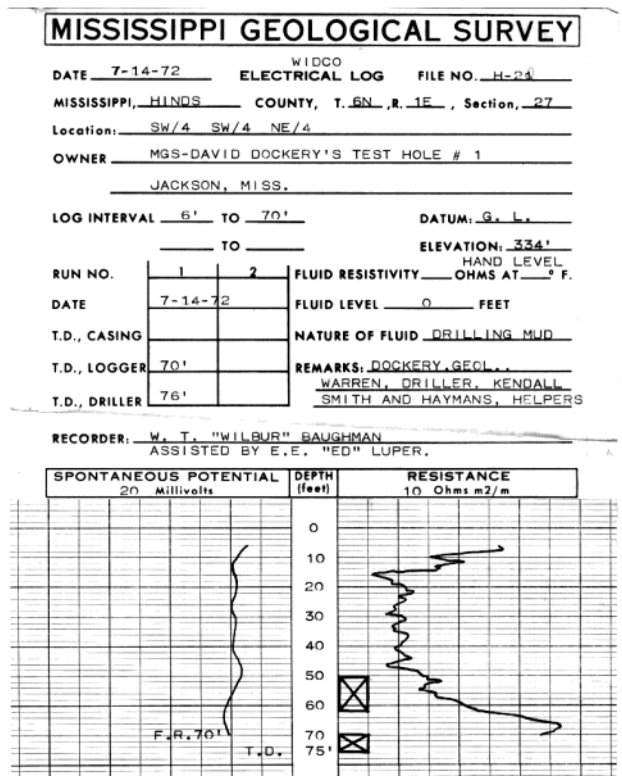


Figure 506. Geophysical log for core hole of the Yazoo-Moodys Branch-Cockfield section at the Mississippi Geological Survey building on 2525 Northwest Street in Jackson, Mississippi. The “X” boxes show the cored interval.

In a report dated April 5, 2012, ARAMARK submitted an “Interior Vapor Intrusion Control Plan” in which the company planned to install “equipment to mitigate potential vapor migrations into the building utilizing an electric powered sub-surface ventilation system” in the southern half of the Woodrow Wilson Boulevard Facility where volatile organic compounds were detected within the perched water-bearing zone below the building’s slab. This plan required: (1) six penetrations cutting through the concrete slab to access the soil below, (2) installation of six collection chamber (sumps) in place with air suction lines installed in each chamber, and (3) installation of static pressure vapor mitigation fans on suction lines to each collection chamber, complete with wiring, differential pressure gauges, and discharge monitoring lines.

Figure 507. Core from a nearby location at the Mississippi Geological Survey building on 2525 Northwest Street, containing Yazoo Clay from 50 to 56 feet 8 inches below ground level in Box 1 at left; Moodys Branch Formation from 56 feet 8 inches to 70 feet 11 inches in boxes 2 and 3 ("X" marks the Moody Branch-Cockfield contact) and Cockfield Formation from 72 feet 11 inches to 76 feet.

A pilot test (two vacuum pressure radius of influence tests) was conducted on July 10, 2012, to test the proposed system. The test indicated that the system might "not create sufficient vacuum beneath the full extent of the concrete slab to prevent vapor intrusion into the building" (letter dated August 22, 2012). The proposed replacement system was one of a "series of interconnected vapor interceptor trenches consisting of 575 feet of interior trench installation through the concrete floor." The trenches would be vented to the exterior by three exhaust fans designed for subfloor radon ventilation.

Moodys Branch Formation, the Canary in the Mine Shaft

John Marble of the Environmental Geology Division of the Mississippi Office of Geology recommended that the Moodys Branch Formation should be the first formation tested for surface pollutants that might penetrate the Yazoo Clay (**figures 505-507**). Marble had the concept of placing monitor wells in the Moodys Branch Formation at schools along the outcrop belt, where students could measure water level and learn about hydrology and protecting the groundwater from pollution. The first monitor well was installed at Jackson Preparatory School in Flowood (**Figure 508**). Marble's recommendation was proven true at the ARAMARK site.

Figure 508. Students and teachers watch as the Office of Geology drills a monitor well in the Moodys Branch Formation at Jackson Preparatory School. Picture was taken on July 31, 2007.

Brownfields

The definition of "Brownfield Site" is given in Section 101 of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Section 9601, definition #39) as: "The term 'brownfield site' means real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant."

Work to address brownfield sites, or brownfields, was spurred on in 1993 when Chicago Mayor Richard Daley and a group of mayors representing The United States Conference of Mayors met with Environmental Protection Agency Administrator Carol Browner to discuss the severe impacts brownfields had on their communities. "Tools" the mayors needed to redevelop brownfields included liability relief for innocent developers and money for environmental assessments and cleanup. Six months later, Browner announced the first EPA brownfield pilot grants. The following year at the 1994 Annual Conference of Mayor in Portland Oregon, the conference held its first Brownfields Forum. In January of 1995, Carol Browner announced EPA's Brownfield Initiative at the Conference of Mayors' Winter Meeting. The initiative established a 50 pilot program, administrative reforms, and the removal of 24,000 "Archived" CERCLIS sites to destigmatize these properties to assist in their redevelopment .

The Brownfields Revitalization and Restoration Act of 2001, S. 350, with strong Whitehouse support, passed the U.S. Senate in April of 2001 by a vote of 99-0. In July of that year the House combined S. 350 with their Small Business Liability Exemption Act, H.R. 2869 and scheduled a vote on the bill on September 11. The bill was rescheduled after the September 11 terrorist attach, and, after some delay, passed the House and then the Senate in December of 2001. President Bush signed H.R. 2869 into law on January 11, 2002, in Conshohocken, Pennsylvania, at a signing ceremony on a former steel mill site (Sheahan and Coley, 2002). It became Public Law 107-118 – "Small Business Liability Relief and Brownfields Revitalization Act."

Swifty Serve #542 Moss Point, Mississippi

EPA's Brownfield and Revitalization website has a section entitled "Success Stories." Mississippi is represented by only one success story (though there are others) entitled "Petroleum Theme Story #2." The story was about former Swifty Serve #542 gas station on Highway 613 in Jackson County, which City of Moss Point purchased in 2002, because it was adjacent property planned for a new convention center.

In 2005, Hurricane Katrina destroyed the gas station along with other properties, making the city a candidate for redevelopment funds from the Federal Emergency Management Agency; FEMA provided $285,000 in aid for redevelopment. The gas station building and fuel dispensers were demolished and removed from the site, but three 10,000-gallon underground storage tanks and the fuel dispenser island and associated piping remained, making a small section in the front of the convention center unusable and unsightly.

In 2007, Moss Point requested additional assistance in the form of Targeted

Figure 509. Underground storage tank removal at the former Swifty Serve in Moss Point, Mississippi (picture from EPA).

Figure 510. Reclaimed land at Pelican Landing Conference Center in Moss Point, Mississippi (picture from EPA).

Mississippi Brownfields 2012

	Brownfield Site Name - Location
1	Amoco/AFTA - Natchez
2	Arizona Chemical – Picayune
3	CECO Building Systems – Columbus
4	City Center – Ridgeland
5	Colle Towing – Pascagoula
6	Copiah Co. MECO Property - Gallman
7	Emerson Appliance Motors Div. - Oxford
8	DeSoto Co. School Bus Lot – Hernando
9	Fabra Care Master Dry Cleaner – Jackson
10	Gautier Oil – Gautier
11	Intex Plastics/Hatco Plastics – Corinth
12	Mound Plantation Red Barn – Rolling Fork
13	Nashville-Ferry Rd/Glenn Springs - Columbus
14	National Picture & Frame/Uniek - Greenwood
15	One Hour Cleaners – Starkville
16	Pennzoil-Quaker State – Vicksburg
17	Pilot Travel Center – Richland
18	Swifty Serve #542 – Moss Point
19	Tupelo Fairgrounds/Longs Laundry – Tupelo
20	W.R. Grace Solvent Waste Site - Corinth
21	West Manufacturers Blvd. - Brookhaven
22	Whirlpool Corp. - Oxford
23	Wolverine Tube - Greenville

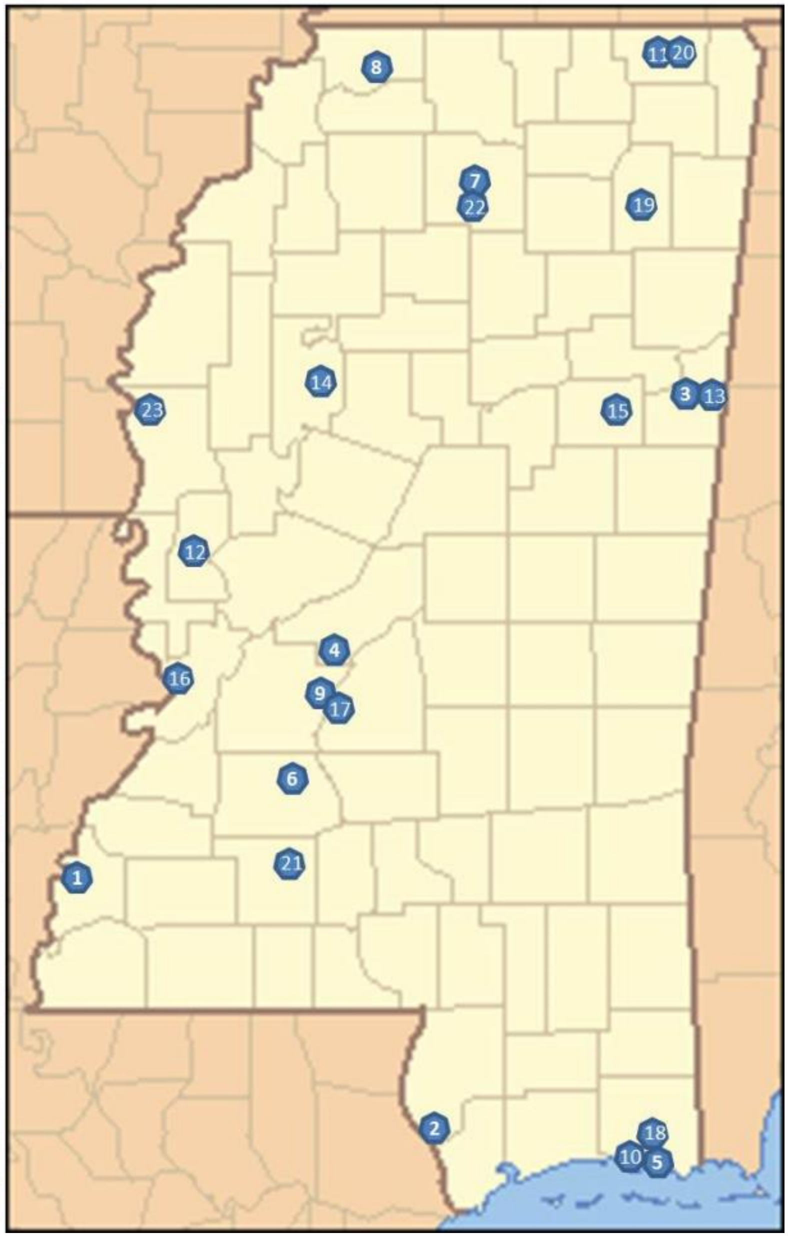


Figure 511. Brownfield sites in Mississippi from the Mississippi Department of Environmental Quality Annual Brownfield Report for 2012.

Brownfield Assessment (TBA) funding from the Mississippi Department of Environmental Quality. This funding allowed the city to determine that the gas station's underground storage tanks were empty, though not properly capped. The city hired a contractor to remove the tanks and associated piping and to cap the property with clean fill (**Figure 509**). Roughly $60,000 worth of assessment and remediation was preformed; the overall cost of the development of the conference center was on the order of $3 million. Today the remediated site provides parking space for 100 cars at Moss Point's Pelican Landing Conference Center (Figure 510). In 2012, there were 23 Brownfields cites in Mississippi (**Figure 511**).

UNDERGROUND STORAGE TANKS

In December1983, the CBS program *60 Minutes* aired a story of rural New England families that lost their groundwater supply due to pollution from leaking underground gasoline storage tanks (**Figure 512**). The narrator, Harry Reasoner, detailed problems caused by leaking service station tanks in Canob Park, a 9-acre development in Richmond, Rhode Island. I (Dockery) watched that program and imagined myself in their situation. The 60 Minutes story must have had the same impact on the other 30 million viewers as it was one of the catalysts that led to the enactment of the Federal underground tank law in November 1984. This law required leak detection and prevention standards for underground tanks. In 1988, owners and operators of existing tanks were given ten years to upgrade, replace, or close those tanks that didn't meet minimum federal requirements. As the ten-year period came to a close, many underground tanks still fell short of federal standards designed to prevent spillage, overfilling, and corrosion. The Underground Storage Tank Energy Act of 2005 provided for: (1) delivery prohibition, (2) operator traing, and (3) secondary containment for new installs.

Benton Site. Just one year after the 60 Minutes program aired, residents of Benton in Yazoo County, Mississippi, complained of bad -tasting and foul smelling water from their public water system. (Much of the following account of Benton's water problem is from an article by Michael Seal [1986] entitled *Investigation of Ground-Water Contamination in a Shallow Aquifer at Benton, Mississippi* published in the June 1986 issue of *Mississippi Geology*.) The Benton water supply consisted of two well fields, the north field and the south field, in the pre-loess terrace sand and gravel overlying the Yazoo Clay. Wells in these fields pumped water from shallow depths of 30 to 40 feet below the ground surface and supplied some 3,000 Benton residents. On February 8 and 15, 1984, the Bureau of Pollution Control sampled the water-supply wells and found them to contain benzene, ethylbenzene, toluene, acetone, 2-butanone, O-xylene, and isopropyl ether. These contaminantes were also found in a private supply well located approximately 2,000 feet south of the north well field. During the week of March 12-16, the U.S. EPA and its contractor did an on-site investigation and collected water, soil, and sediment samples. Results from the samples were not sufficient to determine the source of the contamination. The town of Benton abandoned its water supply wells and connected their public water supply system to that of the Central Yazoo Water Association.

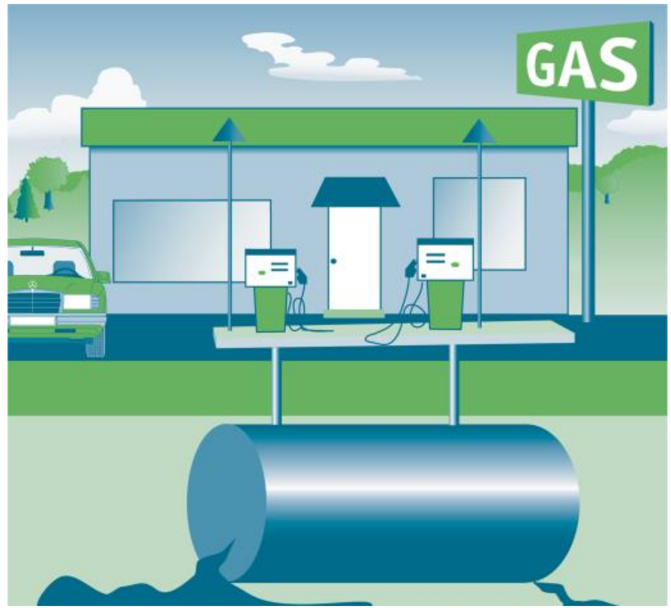
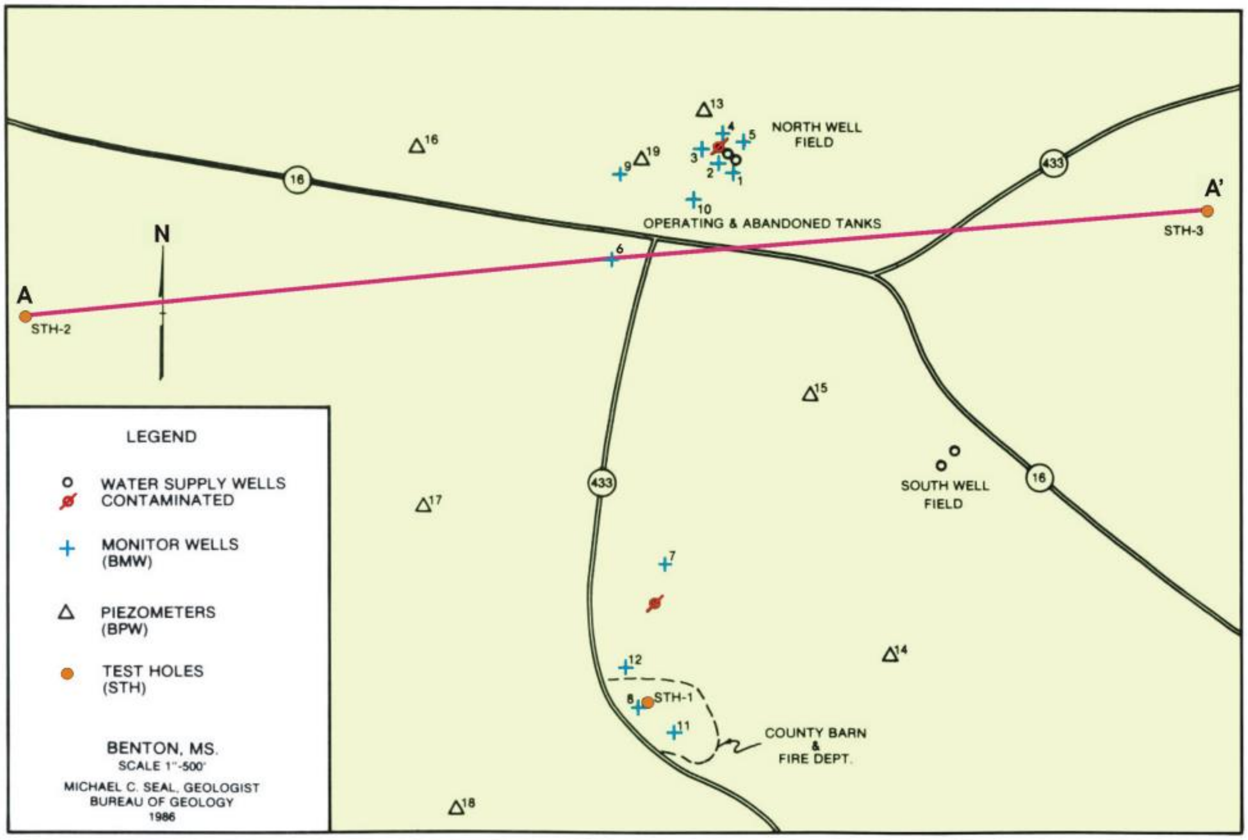


Figure 512. Illustration of a leaking underground gasoline tank from ITRC (Interstate Technology & Regulatory Council). 2005. Overview of Groundwater Remediation Technologies for MTBE and TBA. MTBE-1. Washington, D.C.: Interstate Technology & Regulatory Council, MTBE and Other Fuel Oxygenates Team. Available at http://www.itrcweb.org. Image 2213.

At the request of the Bureau of Pollution Control, the Bureau of Geology began an investigation into the geohydrologic conditions of the Benton ground-water supply in July of 1985. The suspected source of the contamination was a leaking underground storage tank. (Gasoline consists of the contaminants listed above.) Most active and abandoned underground storage tanks in the area were those of gasoline stations concentrated along Highway 16 a few hundred feet south of the contaminated well field. Three stratigraphic test holes (STH) were drilled in a triangular pattern around the study area as were 12 monitor wells (BMW) (**Figure 513** top). **Figure 513** (bottom) gives an east-west cross section through STH-3, BMW-6, and STH-2. The stratigraphic test holes encountered, in ascending order, 33 to 42 feet of loess and clay, 15 to 30 feet of terrace sands and gravels, and 150 feet of Yazoo Clay before encountering the top of the Moodys Branch Formation.

When stratigraphic test hole STH-1, located at the county barn and fire department, encountered the local aquifer, a strong odor of gasoline was noticed by all present (Seal, 1986). Jim Hoffmann of the Bureau of Land and Water Resources remembered the drilling of monitor well BMW-9 just down hill from a



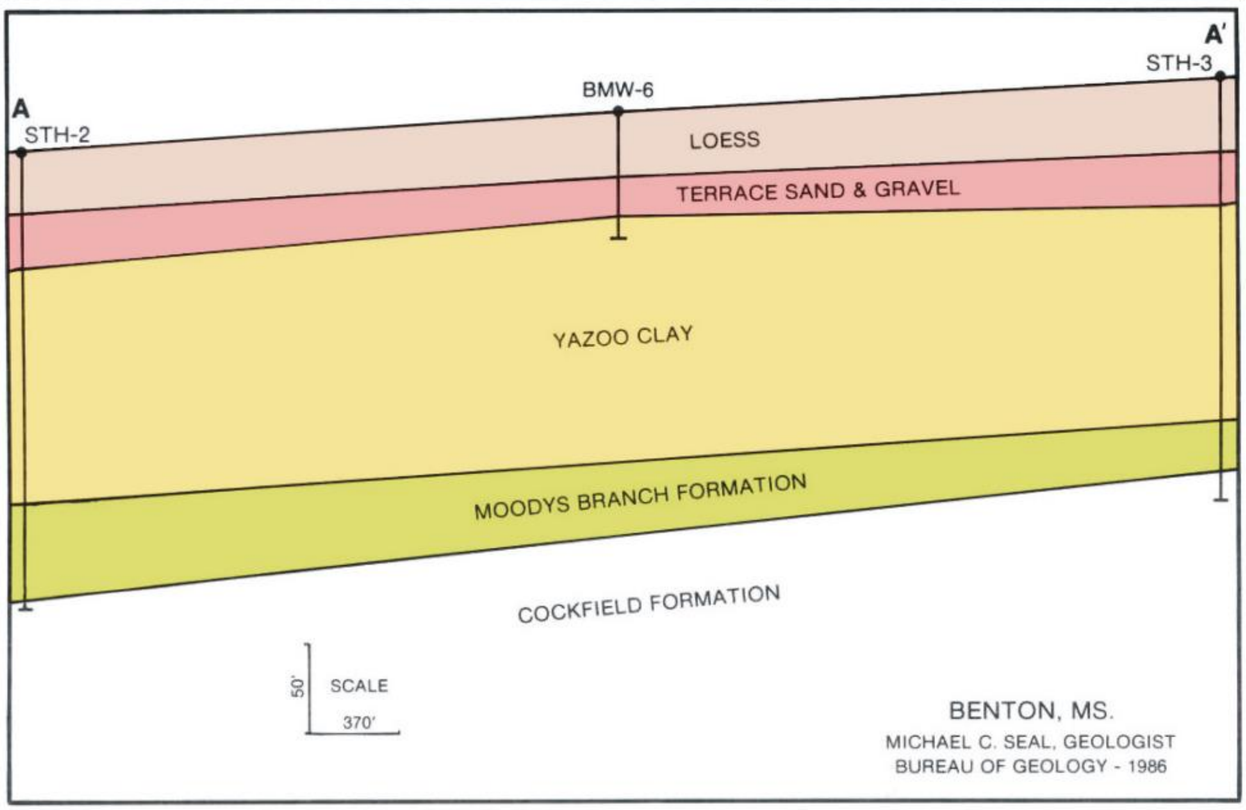


Figure 513. Top, location of wells and test holes in Benton, Mississippi.; Image 2211. Bottom, cross section A-A', through STH-2, BMW-6, and STH-3; Image 2212.

Figure 514. M & M Grocery on Highway 11 at Heidelberg, Mississippi. Picture (color negative; Image 2214) was taken by Mark Taylor on October 7, 1998.

convenience store with gas tanks on Highway 16. The smell of gas was so strong when the rig drilled into the local aquifer that one employee cupped his lit cigarette and scurried from the site. Jim said that the gasoline vapors could be seen rising from the mud pit as they created wavy atmospheric distortions.

The long-term consequence of the underground storage tank leak, or leaks, is that Benton's original well field and groundwater supply in the pre-loess sand and gravel aquifer has been abandoned and the town now gets its water from the Central Yazoo Water Association and the Sparta aquifer. Jim Hoffmann remembered that a couple of years after the town switched from its iron-rich, low-pH, shallow-aquifer water supply to the clearer, higher-pH, Sparta aquifer, that a resident saw his state truck in Benton and ran out of his house in his night clothes to flag him down. He asked Jim when the town was going to go back to its original water supply? Jim asked why he wanted the old iron-rich water. The man said that the new water (rephrased here) tasted terrible.

M & M Grocery Site, Heidelberg, Mississippi. The M & M Grocery (**Figure 499**) leak occurred before the legislation creating the Underground Storage Tank Branch of the Office of Pollution Control and began with a complaint directed to Richard Ball. On October 14, 1985, Ball received a call from a gentleman who said he had a gasoline well on his property in Heidelberg, Mississippi. Heidelberg also has an oil field by the same name, but a gasoline well would be something unheard of for any place. The man's grandsons were accustomed to asking him for money to buy gasoline for their three wheelers. When they quit asking, he asked them where they were getting their gas money. They said they had found a gasoline well.

The gentleman's property contained a spring with a baffled cistern to hold water. The grandkids had been scooping the gas off the top of the water in the cistern for their three wheelers. Ball went immediately to the spring site and found it to contain 1 to 2 inches of gasoline floating above the water. Up the hill from the site was the M & M Grocery, which was both a store and service station. Ball informed the store owner of the gasoline leak; the owner referred him to Sheppard Oil Company who owned the gas pumps and underground tanks and who supplied them with gas. The owner also explained that the Sheppard Oil had been working on their system that

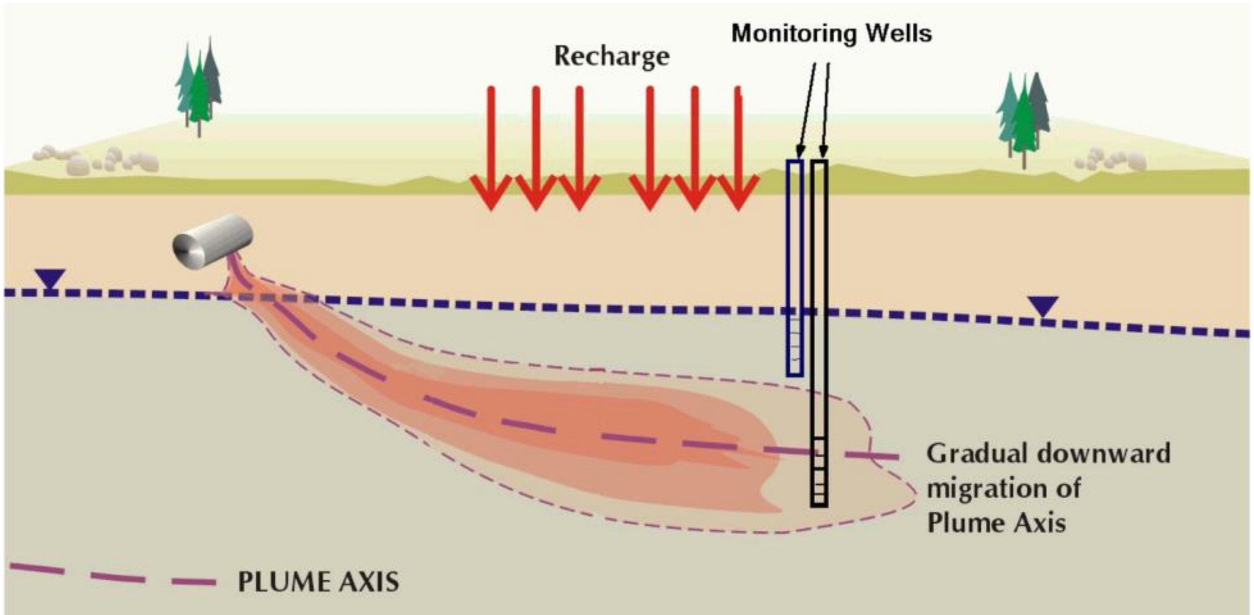


Figure 515. Example of a plunging plume from a leaking underground storage tank. The plume is following the hydrologic gradient downhill from the storage tank, as was the case at the M & M Grocery site, where a natural spring below the site was polluted. Illustration of a leaking underground gasoline tank from ITRC (Interstate Technology & Regulatory Council). 2005. Overview of Groundwater Remediation Technologies for MTBE and TBA. MTBE-1. Washington, D.C.: Interstate Technology & Regulatory Council, MTBE and Other Fuel Oxygenates Team. Available at http://www.itrcweb.org. Image 2216.

weekend and had taken one of the tanks out of service. Before the system check, the station had gone through (terminated) several employees due to missing gasoline (some 3,600 gallons) in their underground tanks.

Upon contacting Sheppard Oil, Ball was told that Southland Oil Company was their supplier and owned the tanks. As the middle man, Sheppard Oil agreed to hire a firm to contain the spill but expressed their concerns that some of the leaking gasoline was coming from two stations down the road. Hughes Drilling of Laurel, Mississippi, was contracted to investigate possible gasoline contamination of soils and groundwater. Installation of 27 monitoring wells began on October 17, 1985, and was completed on October 31, 1985. Gasoline was found in all wells, and recovery began after each well was completed (**Figure 515**). Most of the gasoline was recovered from well number 17, which was 40 feet northwest of the northwest corner of the store and which had a 5-foot thickness of gasoline. A gasoline recovery trench was constructed on the toe of the slope below the store on the northwest corner. Based on data from the monitor wells, Ware Lind Furlow Engineers estimated that as of November 19, 1985, the quantity of gasoline still in the ground was slightly in excess of 3,000 gallons.

Both 1,000-gallon underground storage tanks were removed from the ground at M & M Grocery on October 16, 1985, and the unleaded tank was found to have a small hole, approximately 1/8 inch in diameter, but to be otherwise in good condition. When EPA representatives arrived for a meeting on site on November 6 and 7, 1985, both Sheppard and Southland oil companies agreed to share the cleanup costs.

Figure 516. Hydrocarbon sheen and residue in a natural spring below the M & M Grocery store. Picture (color negative; Image 2215) was taken by Joseph Curro on November 7, 1998.

As of April 28, 1986, over 2,500 gallons of gasoline had been recovered through remediation with the recovery rate at 90 gallons per month. The last line of Ball's memorandum on the site dated April 23, 1986, stated: "A final page will be added to this memo when completion of the cleanup is approved." After that memorandum, the site was turned over to MDEQ's Underground Storage Tank Branch and is in remediation to this date.

In December 1996, a resident complained to MDEQ of gasoline vapors emitting from a wetland area north of his home and near the M & M Grocery Store (now closed). Though Southland Oil had completed their cleanup of the site, 10 inches of gasoline were found in the monitoring well in front of the closed grocery store. Wetlands below the store contained a strong petroleum odor, and there was a definite sheen of petroleum product in a creek that beavers had diverted into the gasoline recovery trench. MDEQ requested that Southland Oil obtain water samples from the hillside spring at the site (**Figure 516**) and perform a Phase I Environmental Site Assessment. Ware Lind Furlow/Aquaterra was contracted to conduct the assessment, which was accomplished the week of May 23, 1997. Borings at the site found samples from 8 feet below surface level to 15 feet below surface level to contain benzene, toluene, ethylbenzene, and xylene. The total benzene-toluene-ethybenzene -xylene (BTEX) was as high as 257 milligrams per kilogram in one sample. The MDEQ action level for BTEX was 100 mg/l in soil samples and 18 mg/L in groundwater samples. In December of 1997, Southland Oil Company installed oxygenated socks to break down the groundwater hydrocarbons; these were removed in January of 1999.

Groundwater sampling and analyses by Aquaterra on January 29, 1999, found BTEX levels above the MDEQ action level of 18 mg/L. Water samples from the spring also had an elevated benzene concentration. Aquaterra initiated a "Limited Phase II and remediation system installation" on October 4, 2000, installing a dual-phase groundwater treatment system with associated piping. Treated water was discharged to an unnamed tributary of Bogue Homo Creek. The remedial system operated from October 4, 2000, to its permanent shut down in April of 2007. On May 29 and 30, 2007, a cistern with a submersible pump and ancillary features was installed to recover and treat benzene contamination entering the spring prior to its outfall on the hillside. The Triannual Monitoring Report No. 21 issued by Aquaterra for the former M & M Grocery facility site (cover letter dated October 26, 2007) concluded that the recovery and treatment system reduced benzene and BTEX concentrations, but never achieved the overall remediation goal. Benzene concentrations in the natural spring remained above the EPA National Recommended Water Quality Criteria of 0.051 mg/L. Aquaterra recommended that spring and groundwater sampling be continued and that additional borings be done to locate the source of the spring-water contamination.

A Bioremediation Feasibility Study by Terracon dated March 12, 2010, found that groundwater samples from the site had an "increased aerobic activity and increased colony counts for microbes specific to hydrocarbon degradation (or metabolism) when introduced in an oxygen rich environment." Terracon recommended injection of ORCa (Oxygen Release Compound) combined with an ammonia-nitrogen amendment to "enhance the growth rate and aerobic degradation of the existing microbes, increasing the natural attenuation rate of the on-site hydrocarbon contamination." Injection activities were performed from July 11-21, 2011. The report concluded that the injection activities "resulted in significantly increased hydrocarbon degradation." Remediation work at the M & M Grocery site continues.

Site Geology. The Jasper County geologic map by Devries (1963) and borings and cross sections by Ware Lind Furlow/Aquaterra (submitted to Southland Oil Company on July 24, 1997) indicate the stratigraphy at the M & M Grocery to include parking lot gravel overlying lenticular: (1) sandy clays to clayey sands, (2) clays with sand seams, (3) silty clay, and (4) clays, all of the Forest Hill Formation, a local aquifer and groundwater source in some places. From south to north across the property, the water table dropped from 383 feet above sea level to 378 feet above sea level in the direction of wetlands to the north. Clays were dominant in the basal part borings at the site into which the "clays with sand seams" appeared to be entrenched in channel-like form.

Murphy Oil USA Store #6857 Site, Clinton, Mississippi. It is only occasionally that Joseph Curro and Dan Harper of the Office of Pollution Control's Underground Storage Tank Program accompany inspector Jeff Rhemann (of the same program) as he inspects underground storage tank facilities. However, this was the case during a routine inspection on December 9, 2010, at Murphy Oil USA's Store #6857 on Highway 80 at the Walmart Store in Clinton, Mississippi. The time was about 9:00 AM, and it was the second inspection of the morning. Harper pulled off the heavy metal cover over the 500-gallon sump containing the unleaded submersible turbine pump. As the cover came up, a hissing sound of escaping pressure could be heard, giving everyone an uneasy feeling. Harper and Curro began unscrewing the knobs that sealed the sump's lid. Before the job was finished, everyone jumped back as gasoline spewed from the sump into the surrounding pea-gravel-filled tank bed. The flow stopped when a customer turned off a gas pump but started again when other customers began pumping gas.

The MDEQ crew turned their attention from inspecting to emergency response. They had the attendant to shut down all the pumps before they removed the sump lid. Inside they found the sump filled with gasoline. Hazard cones were placed around the gas station, and a contractor was called to inspect the submersible turbine pump and make emergency repairs. Even with the hazard cones up, MDEQ personnel had to turn away a continuous flow of drivers, including a school bus, who came for gas. One man was stopped who came with a lit cigarette to use the bathroom.

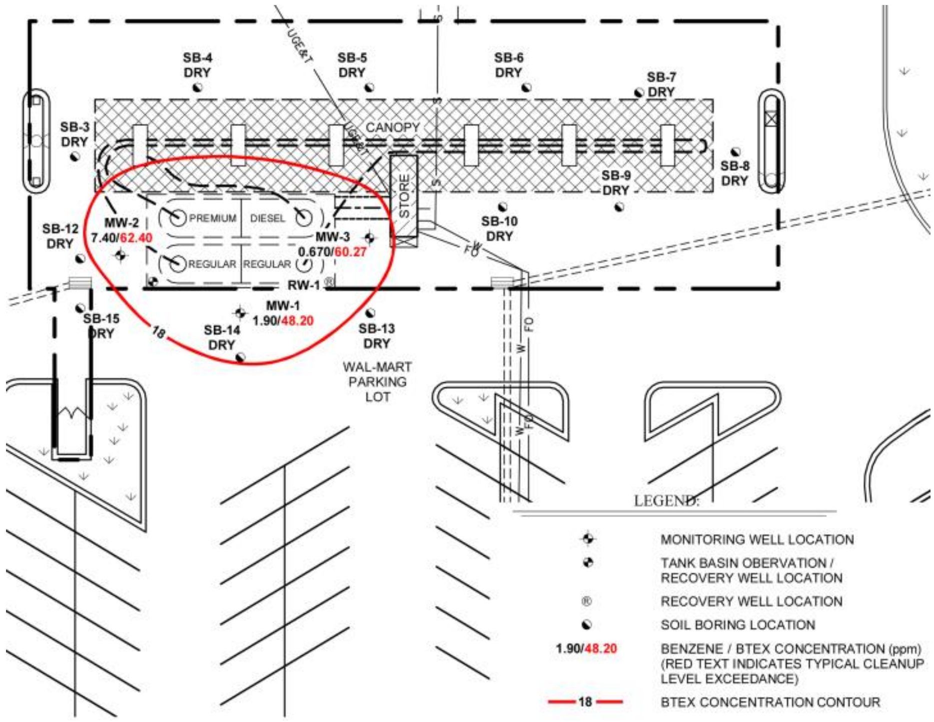


Figure 517. Map view of the Murphy Oil USA #6857 Store on Highway 80 in Clinton, Mississippi, showing monitor and other wells and the extent of BTEX concentrations in the pea-gravel-filled tank pit. Illustration from PPM Consultants report. Image 2222.

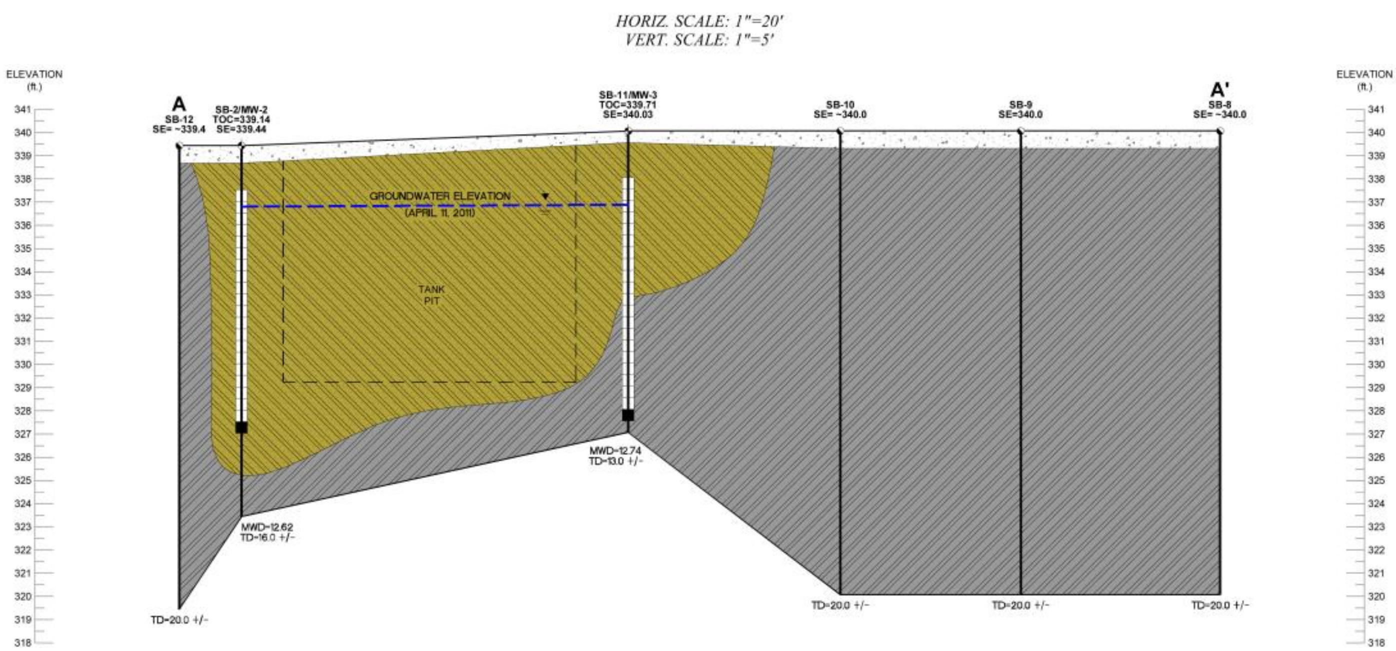


Figure 518. East-west cross section along the length of the tank pit at the Murphy Oil USA Store #6857 on Highway 80 in Clinton, Mississippi. The oversized pea-gravel-filled tank pit is shown in yellow, and the enclosing Yazoo Clay is in gray. The cross section is from a PPM Consultants report. Image 2223.

Figure 519. PPM Consultants geologist Charles Coney in front of the 8-foot high fence surrounding the company's mobile dual phase vacuum extraction system installed at the Murphy Oil USA #6857 Store in Clinton, Mississippi. The new strip of concrete leading to the enclosure covers: (1) a water pipe connecting the system to the storm water runoff drain, (2) plumbing for the vacuum/recovery pipes, (3) electrical lines, and (4) phone/monitoring lines. Picture (digital; Image 2224) was taken on April 10, 2012.

Figure 520. Plumbing from the ground to the mobile dual phase vacuum extraction system at the Murphy Oil USA #6857 Store in Clinton, Mississippi. Picture (digital; Image 2225) was taken on April 10, 2012.

Figure 521. Pressure gauge for vacuum lines leading to the mobile dual phase vacuum extraction system at the Murphy Oil USA #6857 Store in Clinton, Mississippi. Picture (digital; Image 2226) was taken on April 10, 2012.

Figure 522. Interior of the mobile dual phase vacuum extraction system at the Murphy Oil USA #6857 Store in Clinton, Mississippi. Picture (digital; Image 2227) was taken on April 10, 2012.

The contractor arrived within the hour and found that a newly installed o-ring at the check valve of the submersible transfer pump had failed, causing the sump to fill and overflow into the tank bed. When the pump was on, gasoline sent to the gas dispensers was leaking through the o-ring. The pump had been inspected by the contractor only the day before, so the fortuitous inspection by MDEQ employee stopped what could have become a much larger problem. As the tank bed was excavated in the Yazoo Clay, the gasoline remained confined on the site. The gas station's underground storage tank system was installed on August 28, 2002, and consisted of two 20,000-gallon tanks in a single tank pit, which supplied fuel to six dispenser islands under a single canopy (**Figure 517**).

Not long after the gasoline leak was detected, gas fumes became so strong in interior space of the kiosk that remediation was necessary for both the tank bed and store. On December 15, 2010, PPM Consultants, Inc., installed a soil vapor extraction remediation system to remove gasoline vapors from the tank bed. A soil vapor extraction system was also installed adjacent to the store foundation to depressurize the subsoil and prevent gas vapors from entering the store. The tank bed excavation and pea-gravel backfill represented an area of about 3,700 feet; an east-west cross section along the length of the tank bed is given in **Figure 518**. The tank bed and associated utilities at the site were paved over with concrete.

On December 16, 2010, the drilling rig installing an observation/recovery well in the southeast corner of the tank bed hit a shard of concrete within the pea-gravel fill, knocking the shard and puncturing one tank nine feet below surface level. The tank was pumped of its contents, and the tank bed was then dewatered with vacuum trucks and water pumps. An underground storage tank repair company was contracted to fix the double-walled fiberglass tank in place. The repaired tank passed a tightness test on January 7, 2011.

Between March 28, 2011, and March 30, 2011, fifteen soil borings were advanced with a direct push technology rig (Geoprobe), which continuously sampled the section in 48-inch Macro-core sampling sleeves. Outside of the pea-gravel-filled area associated with the tank bed, weathered Yazoo Clay was encountered from beneath the concrete to the total depth of the borings. Pea gravel fill was found to extend beyond the tank bed; the reason for over-sized tank bed was presumed to be due to sidewall failure during construction. Groundwater contained in the fill came from infiltration from the surface and subsequent entrapment by the bounding Yazoo Clay. The top of the water table in the pea gravel was approximately 4 feet below the ground surface.

In 2012, a mobile dual phase vacuum extraction system (DPVE) with a 7.5-horsepower motor was installed at the site and connected to two recovery wells in the tank bed in order to recover residual hydrocarbons. Hydrocarbon vapors were vented to the air, and purified water was piped to the storm drain. An eight-foot high wooded fence was placed around the vacuum extraction system (**Figure 519**). **Figures 520-521** show the above-ground plumbing and vacuum gage connected to the DPVE system. **Figure 522** shows the interior of the mobile system.

CHAPTER 11. SINK HOLES AND KARST HAZARDS

Sinkholes

Figure 523.. Florida sink hole that killed Jeff Bush on Freruary 28, 2013, in Seffner, Florida, reopened on August 19, 2015. Picture from Hillsborough County Sheriff's Office, August 19, 2015. Image 2536.

Figure 524. This cell phone picture taken on March 8, 2013, of Hank Martinez (top), Ed Magaletta (right) and Russ Nobbe (left) looking into a sinkhole to find goff buddy Mark Mihal was published by golfmanna.com. Image 2537.

FISSURES, TUBES, AND CAVES OVER 1,000 FT (300 M) LONG; 50 FT (15 M) TO OVER 250 FT (75 M) VERTICAL EXTENT

- In metamorphosed limestone, dolostone, and marble
- In moderately to steeply dipping beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock beneath an overburden of noncarbonate material 10 ft (3 m) to 200 ft (60 m) thick
- In moderately to steeply dipping beds of gypsum
- In gently dipping to flat-lying beds of gypsum

FISSURES, TUBES, AND CAVES GENERALLY LESS THAN 1,000 FT (300 M) LONG; 50 FT (15 M) OR LESS VERTICAL EXTENT

- In metamorphosed limestone, dolostone, and marble
- In crystalline, highly siliceous intensely folded cabonate rock
- In moderately to steeply dipping carbonate rock
- In gently dipping to flat-lying carbonate rock
- In gently dipping to flat-lying beds of carbonate rock beneath an overburden of noncarbonate material 10 ft (3 m) to 200 ft (60 m) thick
- In moderately to steeply dipping beds of gypsum
- In gently dipping to flat-lying beds of gypsum
- In gently dipping to flat-lying beds of gypsum beneath and overburden of nongypsiferous material 10 ft (3 m) to 200 ft (60 m) thick
- In carbonate zones in highly calcic granite (Alaska only)
- In moderately to steeply dipping beds of carbonate rock with a thin cover of glacial till and frost-derived residual soil (Alaska only)

FISSURES, TUBES, AND CAVES GENERALLY ABSENT; WHERE PRESENT IN SMALL ISOLATED AREAS, LESS THAN 50 FT (15 M) LONG; LESS THAN 10 FT (3 M) VERTICAL EXTENT

- In crystalline, highly siliceous intensely folded carbonate rock
- In moderately to steeply dipping beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock

FEATURES ANALOGOUS TO KARST

- Fissures and voids present to a depth of 250 ft (75 m) or more in areas of subsidence from piping in thick unconsolidated material
- Fissures and voids present to a depth of 50 ft (15 m) in areas of subsidence from piping in thick, unconsolidated material
- Fissures, tubes, and tunnels present to a depth of 250 ft (75 m) or more in lava
- Fissures, tubes, and tunnels present to a depth of 50 ft (15 m) in lava

Areas in which extensive historical susidence has occurred

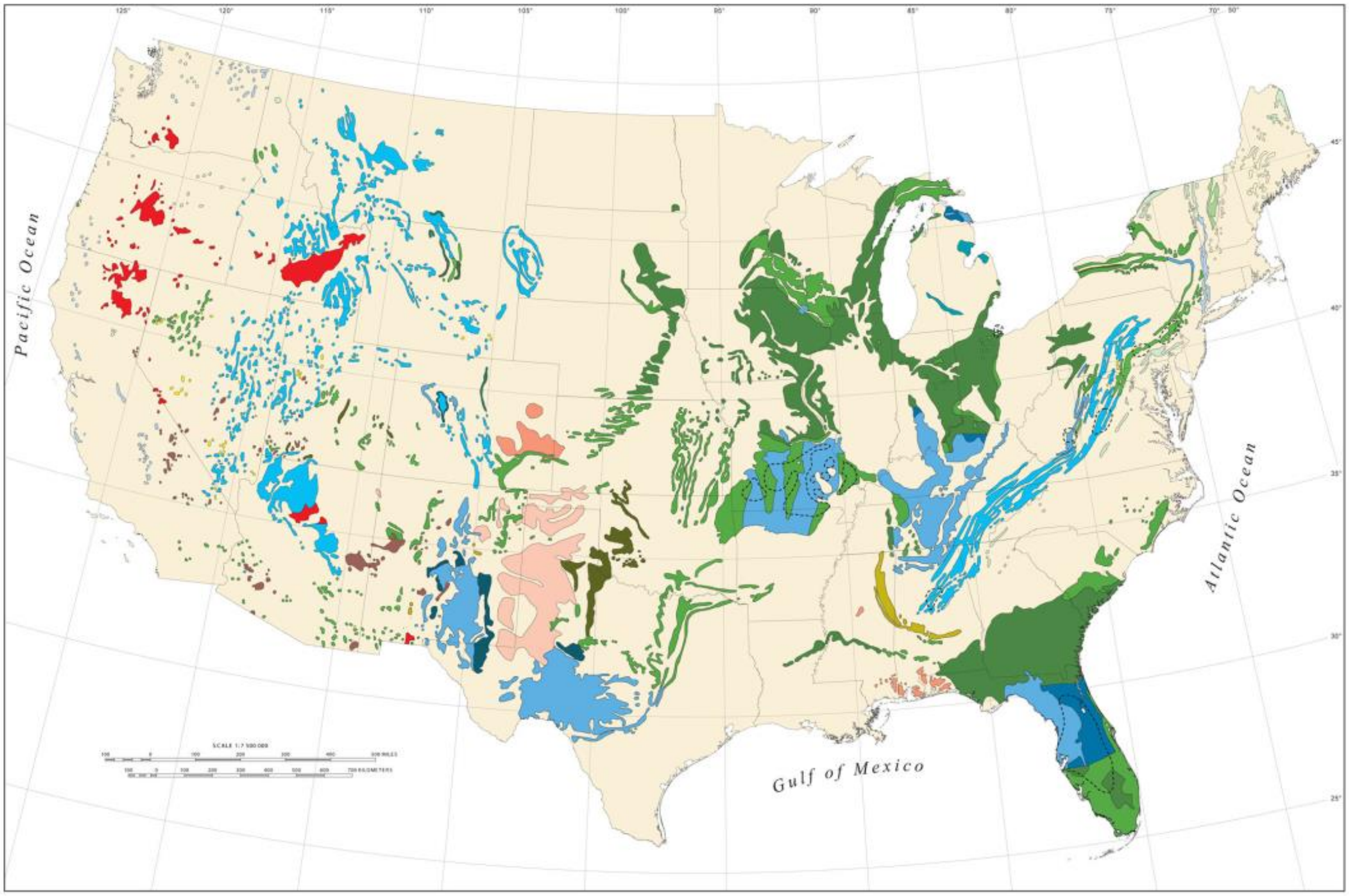


Figure 525. U. S. Geological Survey karst map of the contiguous 48 United States with legend on facing page.

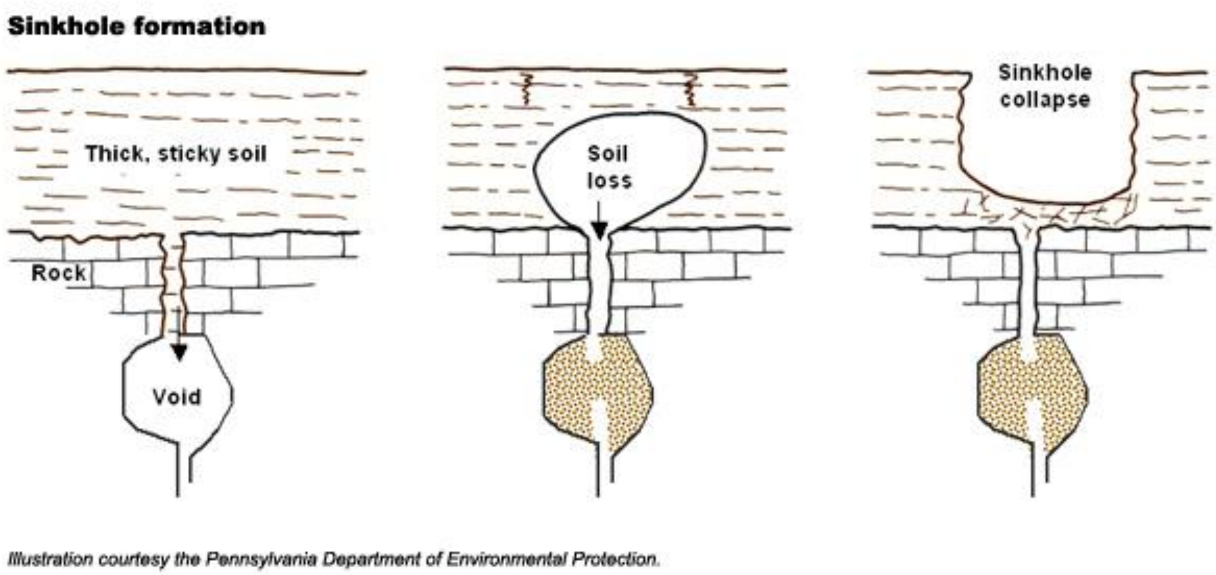


Figure 526. Development of a sinkhole in soil overlying a solution void in limestone bedrock.

Sinkholes. Modified from the April 2013 issue of *Environmental News*, Dockery, 2009, p. 21-25.

Sinkholes, a natural hazard, have been in the news lately after two recent bizarre incidents. First, a Florida man perished when the bed he was sleeping in was swallowed up in a 50- to 60-foot deep sinkhole under his house in Seffner, Florida. As those in the Bush house were going to bed on the Thursday night of February 28, 2013, Jeremy Bush heard a deafening noise and his 37-year-old brother Jeff scream. He ran to his brother's room to find his brother's bed, dresser, and television gone. Jeremy stood in the hole through the collapsed floor and dug through the rubble with a shovel trying to find his bother until the police arrive and pulled him out, saying that the floor was still collapsing. By Saturday March 2, 2013, authorities gave up the search for Jeff Bush admitting at that point it was not possible to recover the body. Then, on March 12, on the 14th hole at Annbriar Golf Course near Waterloo, Illinois, 43-year-old Mark Mihal disappeared down an 18-foot-deep and 10-foot-wide sinkhole. Mark's golfing buddy Mike Peters turned to say something to Mark, and Mark was gone. He heard Mark moaning and ran to find the small hole that swallowed Mark. In twenty minutes Mark was rescued suffering only a dislocated shoulder.

When rescue efforts failed to recover the body of Jeff Bush, authorities demolished the house and backfilled the sinkhole with gravel. The sinkhole reopened two years later on August 19, 2015 (**Figure 523**). The second sinkhole was 17 feet wide and 20 feet deep. The sinkhole that shallowed Mark Mihal in Illinois was not much larger at its opening that the size of the golfer (**Figure 524**). It was excavated and backfilled

Could these things happen in Mississippi? Though not as likely to happen as in the karst terrain of Florida, Illinois, or other limestone-rich states (**Figure 525**), such things could and have happened in Mississippi. Sinkholes in Mississippi are largely caused by sapping of sediment by groundwater, which leaves a void below the surface. **Figure 526**, by the Pennsylvania Department of Environmental Protection, shows how soil moving into a void in limestone bedrock can create a sinkhole. In a similar process, sandy soil in the Mississippi Delta can move into desiccation cracks when the water table drops in the Mississippi River Alluvial aquifer. A tractor once broke an axle when it fell into a sinkhole on a Delta farm near Tutwiler in Tallahatchie County. A paper by Tracy Lusk entitled "Problem of Desiccation Sinking at Clarksdale" in Mississippi Geological Survey Bulletin 97 described a sinkhole in 1957 that damaged the foundation of the new Eliza Clark Elementary School. Drill holes and a test pit indicated the sinking was caused by excess pumping of a well used for the school's air conditioning system, which lowered the water table and allowed sediment from above to move downward into desiccation cracks. Winter rains in 1987-1988, following a drought, produced a "sinkhole" problem in the City of Clarksdale, prompting the city board to seek emergency funds to repair foundations and infrastructure. The August 2, 1988, edition of the *Clarion-Ledger* followed up on the city's grant request under the headline "Stop that sinking feeling."

Sinkholes also develop in the loess soils of the Loess Hills bordering the east side of the Mississippi River Valley. I have such sinkholes where I live in northwestern Hinds County. The trick is to remember where they are and straddle them with the tractor while mowing (so that I don't fall in and break an axle). I tried to fill one of the larger holes with a dump-truck-load of dirt. The dirt went somewhere, and the hole came back. Since then the sinkhole has taken out a pear tree, while working its way up the hill toward my house. Now we use it as a convenient dump for kitty litter in an effort to reach parity with the hole's insatiable appetite for dirt. The left side of **Figure 527** shows cavernous loess in the high wall of a dirt pit on Old Highway 61 in Vicksburg; the right side shows a "rabbit hole" (like the one in *Alice in Wonderland*) leading downward to a loess cavern with another lateral hole draining the cavern. A golfer standing above a slightly covered "rabbit hole" could suddenly find himself eighteen feet below ground at the bottom of a loess cavern. The National Park Service regularly deals with sinkholes and erosion while keeping up the grounds on the loess terrain of the Vicksburg National Military Park. The beautifully manicured slopes require periodic maintenance with heavy dirt-moving equipment (**Figure 528**).

Sinkholes due to solution cavities in limestone also occur in Mississippi, a state with as many as 50 known caves. Caves, sinkholes, and other karst features occur in: (1) the Tuscumbia Limestone in Tishomingo County, (2) the Pride Mountain Formation in Tishomingo County, (3) the Chiwapa Sandstone (in places a limestone) in Union County, (4) the Clayton Formation in Tippah County, and (5) limestones of the Vicksburg Group along the outcrop belt from Wayne County to Rankin

Figure 527. Left, cavernous loess uncovered in the high wall of a dirt pit on Old Highway 61 in Vicksburg, Mississippi. Right, red X at top marks the opening of a "rabbit hole" leading downward to a loess cavern; the lower red X marks a lateral drain leading from the cavern. Pictures were taken by James Starnes on March 22, 2013.

Figure 528. Left, man standing in a sinkhole up to his shoulders at the Vicksburg National Military Park as National Park Service staff and Mississippi Office of Geology personell watch. Right, heavy equipment repairing a slope in the Park. Pictures were taken on April 14, 2010.

County. Figure 4 shows a sediment-filled sinkhole in the top of the Tuscumbia Limestone in Tishomingo County (at left) and solution channels in a limestone in the Pride Mountain Formation in the same county. **Figure 529** shows sinkholes in the Clayton Formation in Tippah County. **Figure 530** shows the inside of Muddy Ridge Cave in the Clayton Formation, which is just down hill from the sinkholes in **Figure 529**. **Figure 531** shows a small cave in the high wall of the old Marquette Cement Manufacturing Company quarry at Brandon.

Karst Terrain and Public Lake Developments

Haynes Lake. Haynes Lake in Tishomingo State Park in Tishomingo County was built in 1963 above the basal limestone of the Green Hill Member of the Pride Mountain Formation. Though the limestone is only five feet thick, it is criss-crossed by solution-eroded

Figure 529. Wil Howie in a dry sinkhole (left) and Suzie Long at a water-filled sinkhole (right) up slope from Muddy Ridge Cave in Tippah County. Pictures were taken in July of 1975.

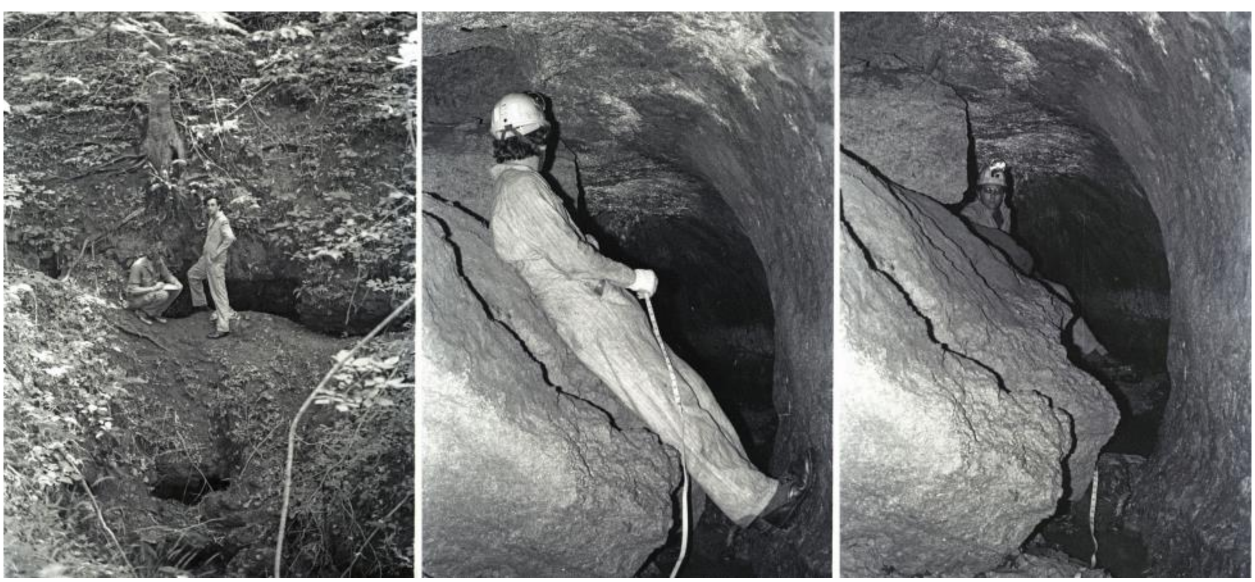
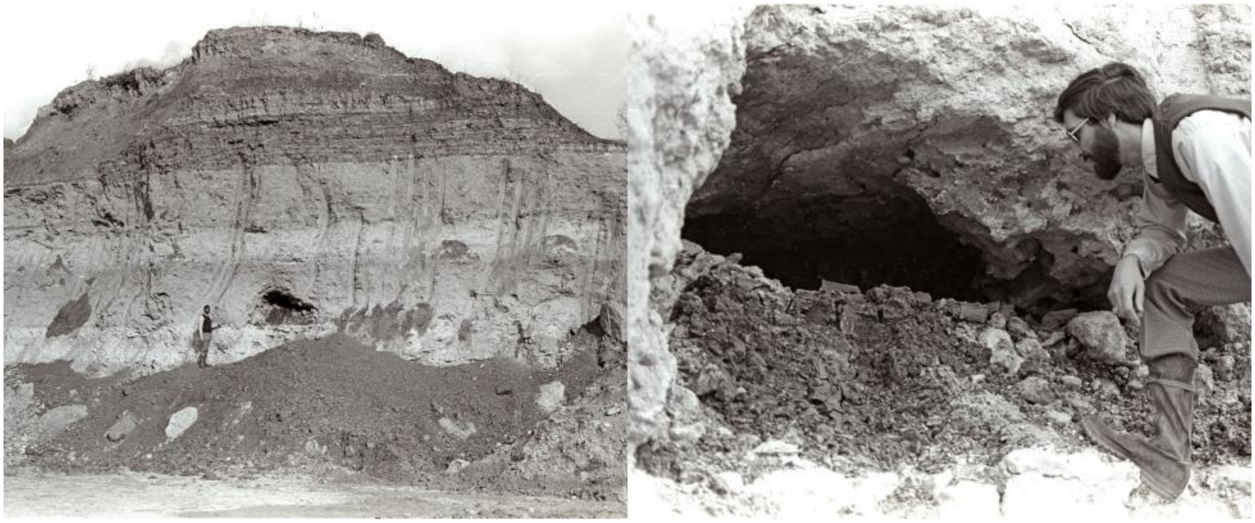


Figure 530. Wil Howie (taking notes) and David Williamson at the entrance of Muddy Ridge Cave in Tippah County (left) and David Williamson surveying the cave passages with a tape and compass (middle and right). Pictures were taken in July of 1975.



531. Left, Michael Bograd's left hand is at the Glendon Limestone-Byram Formation contact with a cave at the base of the Byram Formation to his right. Right, Michael Bograd looks into the narrow cave passage, which is half filled with Bucatunna clay from above. Pictures were taken around February of 1981.

joints systems (**Figure 532**). In 1980, the lake started loosing water down a stump hole to such an extent that a whirlpool formed at the surface and the shoreline retreated at a rate of one foot per day. The resulting flow fed some ten to twelve springs below the dam, the largest of which had a measured flow of 200 to 300 gallons per minute (Curtis Stover, personal communication).

The Mississippi Office of Geology's drilling rig drilled several holes along the shore of Haynes Lake to intercept leaking solution channels in the basal Green Hill limestone. One drill hole encountered a 6-inch solution channel, and two flatbed-trailer loads of cement grout were pumped down this hole for a period of a day and night before the hole quit taking grout. Still, this did not completely stop the leak. The lake was later drained and portions of the bottom were plated with a clay-sand lining (Seal and Stover, 1984). According to Park Worker Supervisor Bob Waldon, who helped grout the lake in 1980, the lake is leaking again down the same hole. Myers and Jennings (2003) documented whirlpools in the present lake where water is draining through limestone fissures and channels.

Smith County Reservoir. A proposed reservoir in the Oakohay Creek watershed of Smith County was promoted as a boost to the county's economy. The suitability of the site was assessed based on three components: (1)

Figure 532. Left, looking down from the dam. Right, looking up toward the spillway at solution channels along joints in the basal limestone of the Green Hill Member of the Pride Mountain Formation below the spillway of Haynes Lake in Tishomingo State Park. Pictures were taken by Stephen Jennings on November 7, 2003.

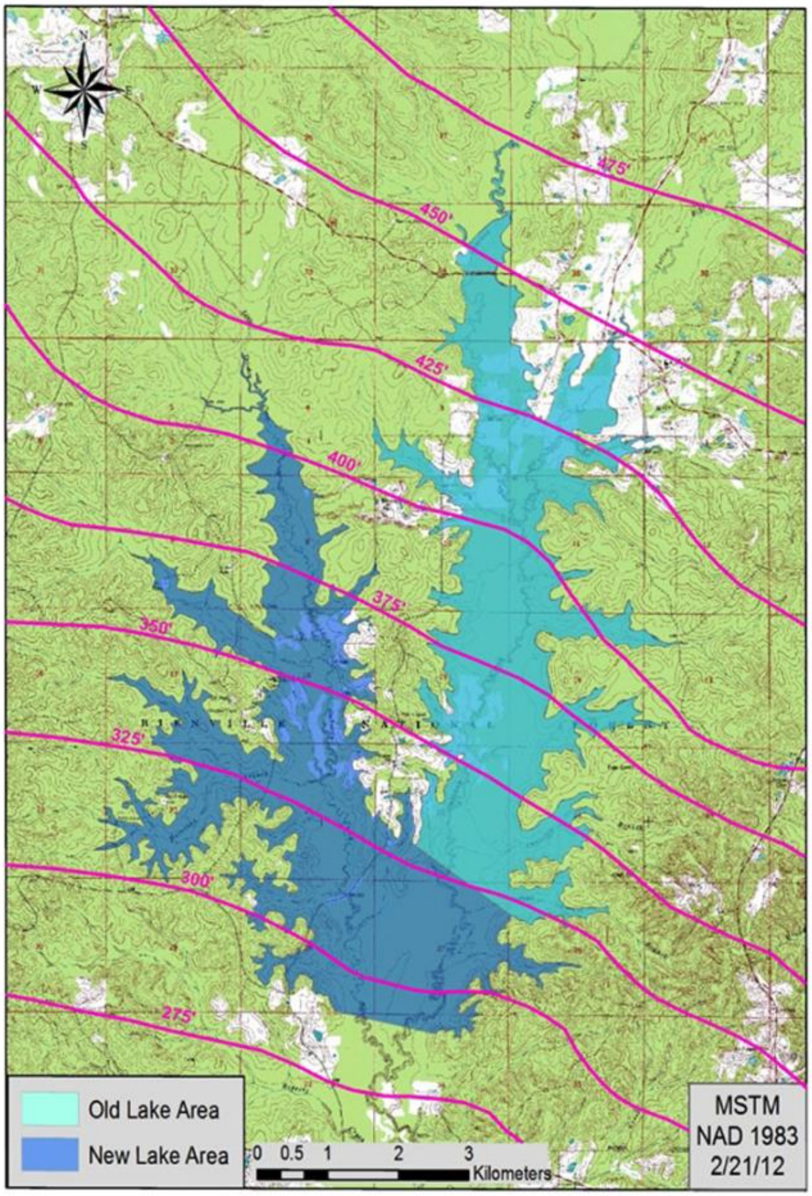


Figure 533. Proposed Smith County reservoir. The original lake proposed is in light blue, and the expanded portion is in dark blue. Contours in magenta on the top of the Glendon Limestone in feet above mean sea level are after Luper (1972, plate 2).

stream discharge at eight locations along Oakohay Creek and its tributaries, (2) the site's geology, and (3) the water quality within the basin. The geologic study included field reconnaissance, surface mapping, and the examination of geophysical log data from MDEQ and from driller's logs from seismic exploration (McIlwain et al., 2007). The drillers logs for seismic holes showed karst features in the Glendon Limestone beneath the proposed dam site. Wells at the dam site lost circulation while drilling through the Glendon interval and some even had pipe to drop through caverns.

To avoid the karst-Glendon substrata, a new dam site was proposed down stream, greatly increasing the size of the lake. **Figure 533** shows the location of the reservoir as originally proposed and as amended to avoid karst features. Magenta contour lines show the elevation of the top of the Glendon Limestone beneath the reservoir in feet above sea level. The proposal for the dam site has some thirty extra feet of cover above the top of the Glendon Limestone.

Proposed Union County Reservoir on Cane Creek

In July 1998, the City of New Albany asked the Tennessee Valley Authority (TVA) to assess the environmental consequences of alternatives for meeting the future water needs of New Albany and Union County. One of those options was to build a multi-purpose Reservoir northeast of New Albany on Cane Creek as a public water supply source. On June 2000, TVA published the Final Environmental Impact Statement on the proposed reservoir. The project was abandoned largely due

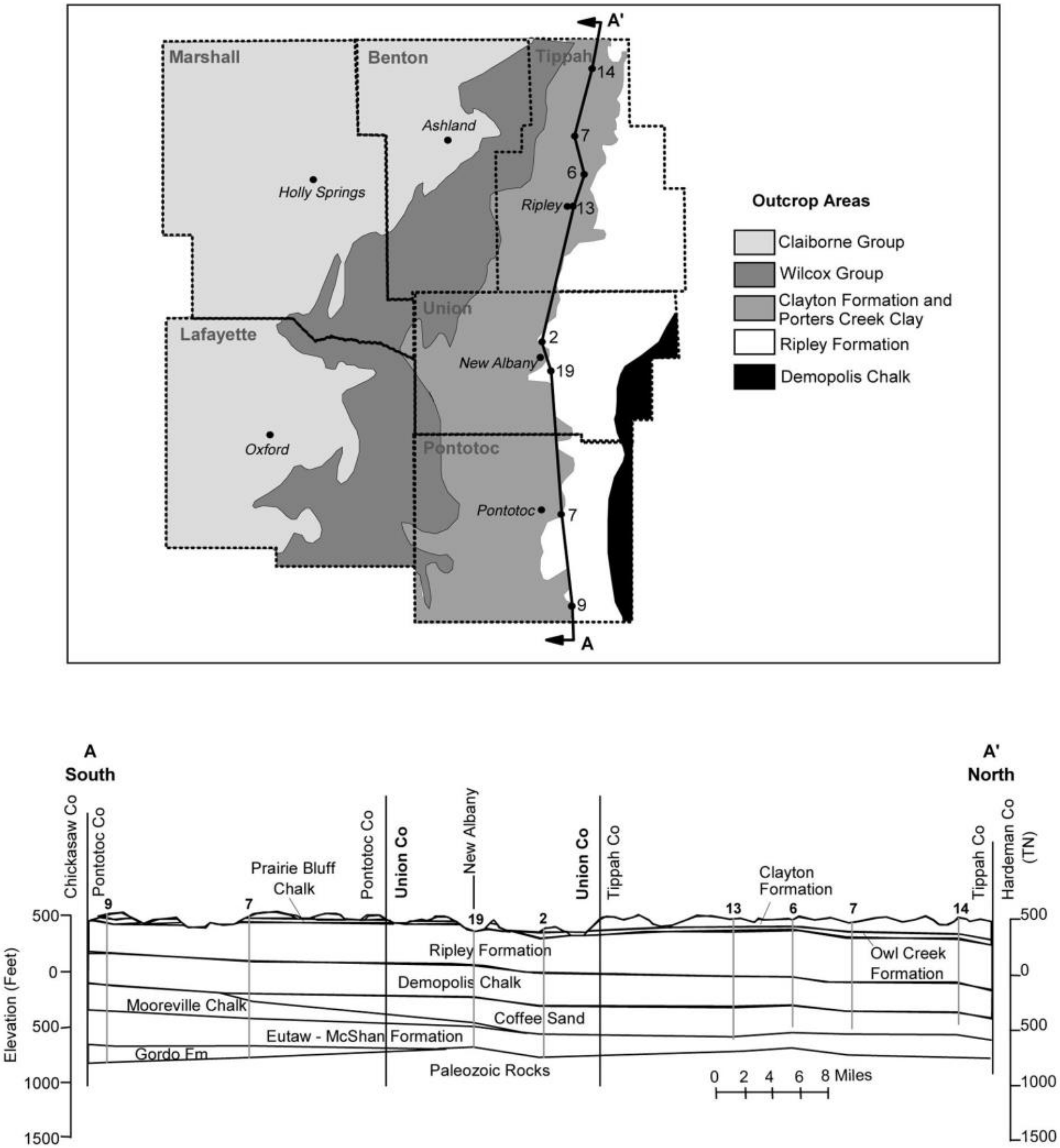


Figure 534. Geologic map (a generalization of a portion of the 1:500,000-scale state geologic map by Bicker, 1969) and cross section of a six-county area around the proposed Union County Reservoir location from the Geology Section (3.1.1) of the TVA Environmental Impact Statement, 2000.

to the cost and to the fact that the area had adequate groundwater supplies. A secondary, but very important, reason the project was abandoned is the fact that the lake bottom and dam site rested above the Upper Ripley Formation as mapped in the Union County Mineral Resources Bulletin (Conant, 1942), which included karst features in the Chiwapa Sandstone (**Figure 534**).

Conant (1942, p. 28) described the upper Ripley in Union County as follows: "The limestone of the upper Ripley crops out conspicuously in many places, especially on steep hill slopes and in some road cuts. About 1 mile northwest of Parks (E. edge, Sec. 8, T. 7 S., R. 4 E.) portions of it have been dissolved, producing broad flat "caves" which penetrate the hills a few tens of feet. The lower reach of the proposed reservoir and the dam site are in Section 27, T. 6 S., R. 3 E., about 5 miles northwest of the cavernous locality reported by Conant.

Mellen (1958) named the upper Ripley limestone of Conant (1942) the Chiwapa Sanstone Member of the Ripley Formation. He described this unite as: "It is characteristically a "bored" or horsebone" limestone or calcareous sandstone, an irregulary indurated stratum of shallow marine sediment approximately 80 feet in thickness at the top of the Ripley, and it can be traced for a north-south distance of 85 miles, more or less." Mellen illustrated the openings of two caves at a locality (noted by Stephenson and Monroe, 1940. p. 194) named "The Caves" in the north half of Section 1, T. 7 S., R. 3 E., in Union County. This locality is only about 2.5 miles southeast of the proposed dam site (**Figure 535**).

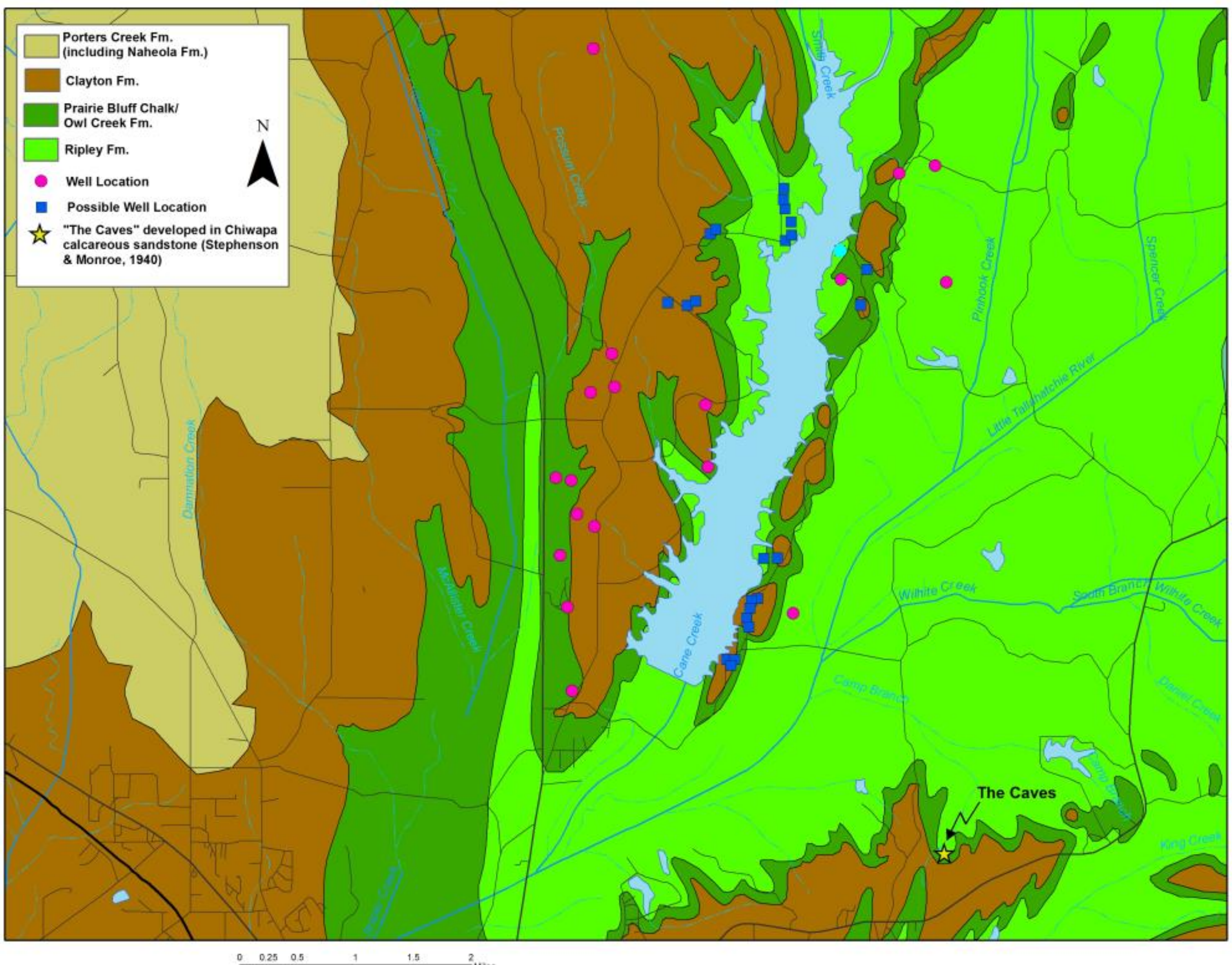


Figure 535. The proposed reservoir and a locality called "The Caves" (lower right) are plotted on the 1:95,040-scale Union County Geologic Map by Conant (1942); the location of adjacent water wells are from the Geology Section (3.1.1) of the TVA Environmental Impact Statement, 2000.

CHAPTER 12. DAM SAFETY

Major U.S. Dam Failures

South Fork Dam. The greatest loss of live from a dam failure in the United States occurred in Johnstown, Pennsylvania, on May 31, 1889, due to the catastrophic failure of the South Fork Dam situated some 14 miles upstream from the town on the Little Conemaugh River. The failure was largely one of engineering design and maintenance, which was not sufficient to accommodate a record-rainfall event. The dam was originally built by the Commonwealth of Pennsylvania as part of a cross-state canal system. When railroads replaced barge traffic, the state abandoned the canal system and sold the dam and reservoir to the Pennsylvania Railroad, which then sold the property to private interests. One of the latter owners removed the dam's original three cast iron discharge pipes that allowed a controlled release of water and sold the pipes for scrap.

Figure 536. View of Lake Conemaugh from downstream side of South Fork Dam. Picture from the Johnstown Flood Museum Photo Gallery.

The reservoir, Lake Conemaugh (**Figure 536**), was then sold to speculators who raised the lake level, built cottages and a clubhouse, and created the South Fork Fishing and Hunting Club in 1881. At this time the dam was 72 feet high and 931 feet long. Between the opening of the club and 1889, the dam frequently sprang leaks, which were patched with mud and straw. One reservoir modification that contributed to the disaster to come was the fish screen that was built on the lakeside of the spillway. The reservoir was stocked with expense game fish, and the screen kept the fish in the lake but also collected debris (**Figure 537**).

The morning of May 31, 1889, the president of the South Fork Fishing and Hunting Club awoke to find the reservoir nearly cresting the dam after a night of heavy rain. In pouring rain, he quickly assembled a group of men to unclog the broken fish screen and debris from the spillway but without success. Twice telegrams were sent from the nearby town of South Fork to warn official in Johnstown that the dam was eroding. Because of similar false alerts given in past storm, the warnings were not passed on to the town authorities. Work to save the dam continued until 1:30 p.m., when the club president pull his

Figure 537. A canoe on Lake Conemaugh at the South Fork Fishing and Hunting Club. The fish screens are visible by the canoe; the spillway is off-camera to the left. Picture from the Johnstown Flood Museum Photo Gallery.

Figure 538. View of the broken South Fork Dam from the empty lake, showing former level of the dam and lake. Picture from the Johnstown Flood Museum Photo Gallery.

Figure 539. Dried lake-bottom mud and the breached South Fork Dam. Picture form the Johnstown Flood Museum Photo Gallery.

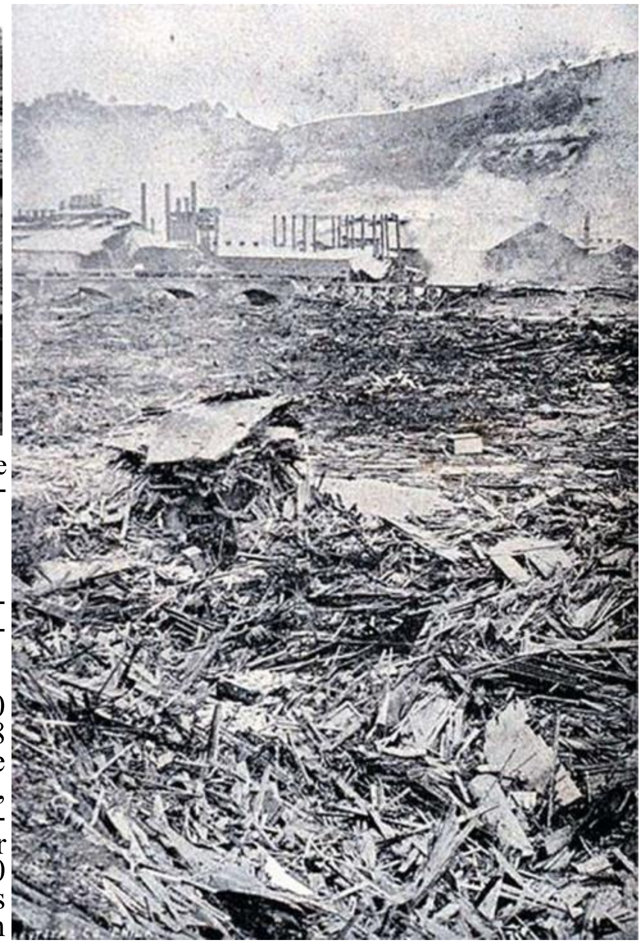


Figure 540. Debris field above Stone Bridge on the Pennsylvania Railroad (NOAA).

men back to high ground and safety. In Johnstown local flood water as high as ten feet already had people trapped in their houses.

South Fork Dam collapsed around 3:10 p.m., unleashing 20 million tons of water (4.8 billion U.S. gallons) downstream from the Lake Conemaugh reservoir toward Johnstown, a flood surge that temporarily equaled the volumetric flow rate of the Mississippi River (Perkins, 2009). The entire lake drained in 40 minutes (**figures 538-539**). South Fork was the first town hit. It was situated on high ground, and most of the town's people were save by running to the hills when they saw the dam spill over. When the flood reached the village of East Conemaugh, it was so full of debris that a witness standing on high ground said it looked like a huge rolling hill. A locomotive engineer heard the flood coming, tied down his whistle, and raced his train backward through East Conemaugh, saving many people who raced for higher elevations. The flood picked up the locomotive, but the engineer survived.

Just before the flood surge reached Johnstown, it hit the Cambria Iron Works and the Gautier Wire Works in the town of Woodvale. The flood exploded boilers and picked up miles of barbed wire, which became entangled in the debris.

Fifty seven minutes after the failure of the South Fork Dam, the flood surge hit Johnstown catching residents largely by surprise. A wall of water and debris reaching heights of 60 feet in places raced through Johnstown at a rate of 40 miles per hour until it became impounded behind the Stone Bridge that carried the Pennsylvania Railroad. The bridge held, creating a second surge that rolled upstream along the Stoney Creek River and then back again to the bridge. Debris trapped behind the bridge caught fire and burned for three days. When the flood receded, the debris field at Stone Bridge covered 30 acres and reached as high as 70 feet (**Figure 540**). In total, the flood caused $17 million in damages and killed 2,209 people. It was the first major disaster relief led by Clara Barton and the new American Red Cross.

Survivors of the flood suffered legal defeats in their attempts to recover damages from the dam's well-connected owners. The dam failure was judged to be "An Act of God" caused by the heaviest rain on record in that part of the country, 6 to 10 inches in a period of 24 hours. Public outrage at the judicial system led to a change in American law from a fault-based regime to strict liability.

Figure 541. Photograph of St. Francis Dam before its collapse. Construction of the dam began in 1924 and finished in 1926. The dam failed right before midnight on March 12, 1928. The photograph is from the Los Angeles Bureau of Power and Light as contained in the U.S. Geological Survey Photographic Library.

St. Francis Dam. The St. Francis Dam failure was a geologic disaster caused by unstable formations at the dam site. It was brought on by the need to supply more water to the growing City of Los Angeles. In the early 1900s, the availability of water was key to the city's growth and to its transformation into a modern metropolis in a semi-arid region. Under the direction of Superintendent William Mulholland, a self-taught engineer, the Bureau of Water Works and Supply, irrigated larger areas of the city with water obtained by the city in a buyout of water rights outside the city limits. Mulholland oversaw the constructed 233 miles of the Los Angeles Aqueduct, which carried water from the Owens Valley in the Eastern Sierra to a reservoir in the San Fernando Valley.

In the 1920s, Los Angeles' pursuit of water rights and the diversion of the Owen River precipitated the California Water Wars. After seeing city employees destroy the dams and locks of their irrigation systems, the farmers of Owens Valley fought back. On the morning of May 21, 1924, the Los Angeles Aqueduct was destroyed by dynamite at a critical point at Jawbone Canyon. Sabotage by the valley's residents continued for months. On November 16, 1924, farmers seized control and shut a critical aqueduct gate. They were joined by some 700 hundred of their friends and neighbors in a press event covered around the world. The city was forced to negotiate a piece. When a second resistance occurred in 1927 with the demolition of a 45-foot section of the aqueduct, guards were sent out on horseback patrols to protect the system.

Several reservoirs were built to supply the Los Angeles Aqueduct. Hollywood Reservoir was the first to have a concrete dam, a dam named after its engineer—Mulholland Dam. Construction on the dam began in August of 1923 and was completed in March of 1925. There was then need for a even greater reservoir to carry the city through a period of drought, one that could contain a year's supply water. Mulholland's selection for the dam site was between Powerhouses No. 1 and No. 2 in San Francisquito Canyon.

Figure 542. After the St. Francis Dam failure, only the middle section of the dam, a section known as the "Tomb Stone," was left standing. The contact of the Pelona Schist and Vasquez conglomerate, the location of the inactive San Francissquito Fault, is visible to the left of the dam remnant. Picture was taken on March 17, 1928 (U.S. Geological Survey Photographic Library).

The name for the new dam, St. Francis Dam, was an Anglicization of the canyon's Spanish name. It was designed and built between 1924 and 1926 as a curved concrete gravity dam. The dam location chosen by Mulholland was not based on the site's geology but on the favorable topography.

The geology of the dam site proved to be disastrous. On appearances, the sedimentary Vasquez conglomerate of the west valley wall and the dam's west abutment seemed to be strong and resistant as it held up prominent high topographic ridges. This was true in the region's semiarid environment, but the rocks disintegrated when they became water saturated. The Pelona Schist of the east valley wall was foliated parallel to eastern slope and showed signs (signs noted after the fact) of recent and ancient instability and landslides. In fact, the east abutment rested against a section of an ancient landslide. Dividing these the formations of the east and west was the inactive San Francisquito Fault, located below the dam under the west abutment. When the reservoir began to fill, water seeped through this area of the dam. A two-inch pipe was laid from the fault line at the dam to the dam keeper's house where it the water was used for domestic purposes.

As first planned St. Francis Dam was to have a height of 175 feet above the floodplain, which would impound 32,000 acre-feet of water. After construction began, plans were changed to give the dam a height of 185 feet above the floodplain to hold a reservoir of 38,000 acre-feet. There was no modification in the base of the dam to accommodate the increased height and a 588-foot-long wing dike had to be constructed along the ridge of the western abutment to keep the water from flowing over.

On March 1, 1926, water diverted from the Owens Valley Aqueduct began filling the reservoir, causing temperature-related contraction crack in the dam and minor seepage under the abutments. In April the water level reached the inactive San Francisquito Fault line, and the dam began to leak at that point immediately. Worker were only partly successful in sealing the leak. Drainage pipes under the dam carried away water to relieve the hydrostatic pressure at the base of the dam and, thus, to prevent lift. Water from the dam was used to supply the Los Angeles Aqueduct after sections of the aqueduct in Owens Valley were dynamited in May 27; between 7,000 and 8,000 acre-feet were diverted. On March 7, 1928, the lake level was three inches below the spillway and no more water was turned into the reservoir (**Figure 541**).

On March 12, the dam keeper found a new leak in the western abutment. This leak concerned him due to its muddy color, indication erosion of the dam foundation. Mulholland was alerted, and both Mulholland and assistant chief engineer Harvey Van Norman inspected the leak, which surged and waned with a discharge of 2 to 3 cubic feet per second. They were relieved to find that the leak came from the dike section atop the Vasquez Sandstone and was clear at its source and muddy after cascading over loose fill from the old construction road. Mulholland determined that corrective measure would need to be taken at some time but that the dam was safe. Mulholland and Van Norman returned to Los Angeles.

St. Francis Dam failed catastrophically at two and a half minutes before midnight on March 12, due to a landslide of the Pelona Schist along the dam's left abutment (**Figure 542**). A mass of 1.52 million tons of schist moved against the dam's 271 thousand tons of concrete (Ropers, 2007a) (**figures 543-544**). The time was recorded by a drop in voltage from Power House #2, as noted by those working at Power House #1. A 140-foot-deep flood wave raced down the canyon killing at least 420, of which 179 were never recovered. Estimates of those killed are as high as 600. The dam keeper and his family were the first victims; then 64 of the 67 workers of Power House #2 were next. The flood traveled down the canyon to the Santa Clara riverbed where it demolished the Southern California Edison Saugus substation, leaving the region without power. Next the flood

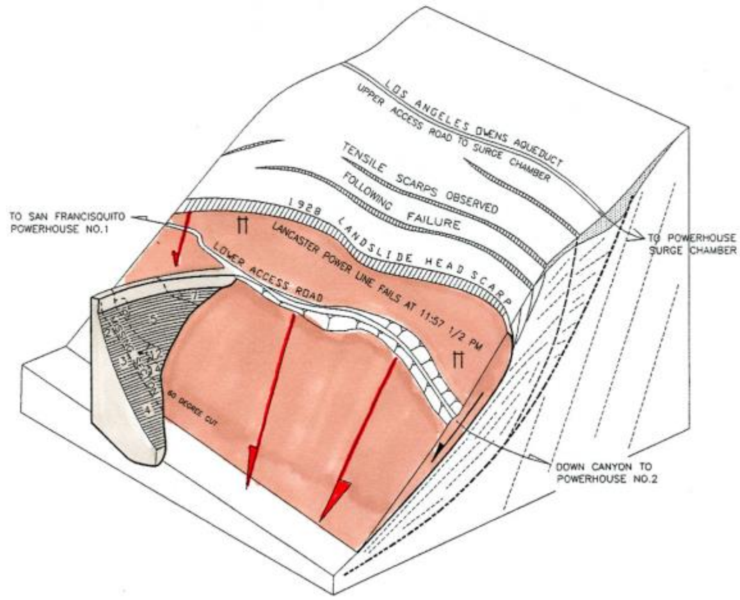


Figure 543. Diagram of the ancient landslide under the left (east) abutment of St. Francis Dam and the landslide in the Penola Schist that caused the dam's failure, from Rogers (2007, figure 26).

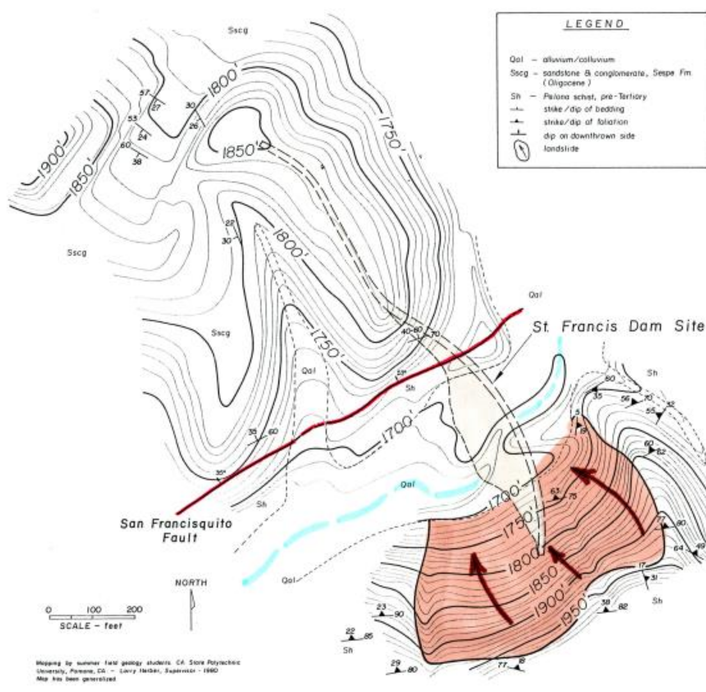


Figure 544. Map view with topography of the St. Francis Dam site; the Penola Schist landslide is shown in red, from Rogers (2007, figure 23).

washed away the town of Castaic Junction and then a temporary construction camp, where 84 of 150 men perished. Warnings were sent out before the waters devastated much of the towns of Fillmore, Santa Paula, and Bardsdale. In only 5 hours and 27 minutes the flood waters covered 54 miles between the reservoir and the Pacific Ocean before dumping its debris and victims at sea. Bodies of flood victims were found in the Pacific as far south as the Mexican border.

The Governor's blue ribbon Board of Inquiry into the cause of the dam's failure included two geologists: Professor Leslie Ransome of Cal Tech and George Louderback of U. C. Berkeley. Louderback was critical of the dam's placement across the San Francisquito fault. Ransome was more critical of the Vasquez Formation's tendency to swell and slake upon submersion, due to its gypsum content. A favorite ploy of prosecuting attorney's attacking the city and Mulholland was to drop the arkosic sandstone into a glass of water and let the court witness its disintegrate. The Governor's Board decided that the cause of failure was hydraulic piping through the dam's right abutment. This decision was based in an erroneous recognition that the dislocated dam block that straddle the fault on the right abutment, Block 16, was further downstream than were the blocks from the left abutment, blocks 12 and 14.

In a reconstruction of the dam failure based on physical data, Rogers (2007), gave compelling evidence that a landslide at the left abutment initiated the failure. The Borel Power Line was severed in the east abutment landslide, where the lines grounded out at 11:75-1/2 PM. Also, the left abutment was carried across the central portion of the dam, up onto the right abutment, and the dam's largest displaced blocks rested on an enormous volume of schist detritus. Another critical point was the account of the Ray Silvey family, who crossed the road above the dam's east abutment about three hours before the dam failed; they were stopped by a foot-high scarp across the road and had to excavate ramps for their tires. The Governor's Board quick decisions and report release got the most publicity and was most quoted after the fact.

The magnitude of the St. Francis Dam failure disaster, led to several safety benefits from the lessons learned, including (from Rogers, 2007):

1. Engineering geologic input on dams became commonplace in the 1930s, whereas it was all but absent in the 1920s.
2. The federal government ordered a through safety inspection and review of all their dams due to the public outcry from the St. Francis Dam failure.
3. Publication on the "Geology of Reservoir and Dam Site" by the U.S. Geological Survey in 1928 (Water Supply Paper 597-A).
4. Engineering geologic input became mandatory for all high dams. The Bureau of Reclamation hired first full-time engineering geologist to work at Hoover Dam in 1931. The Corp;s of Engineer, the Tennessee Vally Authority, and the California Division of Water hired engineering geologists, respectively, in 1931, 1933, and 1934.
5. The American Society of Civil Engineers convened a special Symposium on High Dams at their annual meeting in San Diego in October 1928.
6. The American Institute of Mining and Metallurgical Engineering sponsored a technical symposia on Geology and Engineering for Dams and Reservoirs at their annual meeting in New York in 1929.
7. The Boulder Canyon Project Act (to build Hoover Dam), which passed the U.S. House of Representatives on May 15, 1928, failed in the Senate due to a filibuster by Arizona and Utah senator fearful of another "St. Francis Dam catastrophe," until a late May compromise was reached. The Colorado River Board was created to review plans proposed for the Boulder Canyon Project; the board chose Black Canyon rather than Boulder Canyon for the dam site.
8. The California Legislature passed California Dam Safety Legislation on August 14, 1929, which required state inspection of dams. Between 1929 and 1931, 827 dams were inspected, only a third of which were found to be adequate.
9. The California legislature passed the Civil Engineers Registration Bill in early July 1929, which became law on August 14, 1929, and created The Board of Registration for Civil Engineers. Some 5,000 engineers were registered by June 30, 1930, providing the State of California with one registered engineer for every 1,000 people living in the state.
10. State-mandated arbitration hearings for victims of natural disasters. The state enacted special legislation to adjudicate financial compensation to victim's surviving

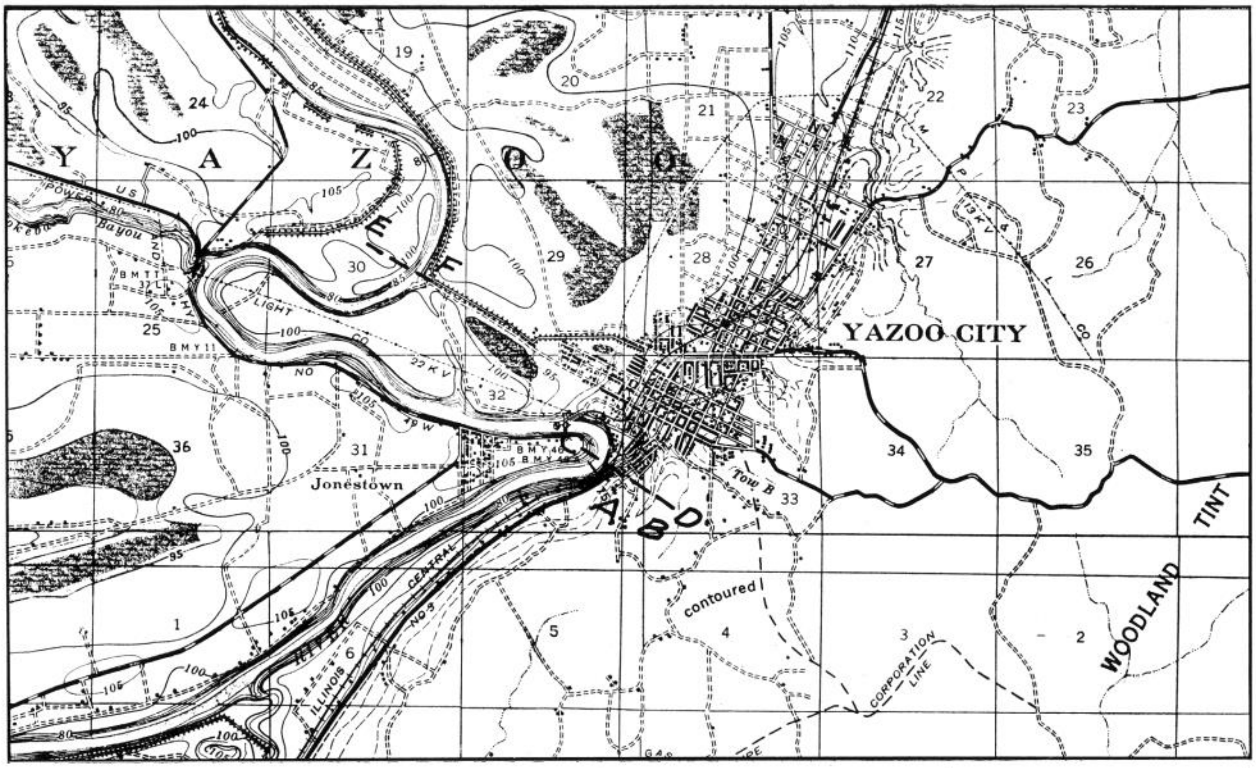


Figure 545. Topographic map of Yazoo City with only a part of the bluff contoured. A and B mark two ridges that parallel the river trending southwest to northeast, both of which have significant landslides. C-D marks the location of the proposed Highway 49 bridge. Dr. Morse steered Highway Department engineers away form the proposed site to a site at E-F where the Highway 49 bridge is today. Map is Plate 1 in Mississippi Geological Survey Bulletin 27 (Morse, 1935).

next-of-kin, omitting compensation to attorneys. This legislation was used by the State Attorney General's Office to effect a reasonable process of compensating victims of natural disasters in the northern California floods of 1955 and 1956 and in the 1989 Loma Prieta earthquake.

11. The construction of San Gabriel Dam at The Forks Site was stopped in 1929, and the project became the first dam cancelled by the State of California after an independent inquiry report stated that the dam, "cannot be constructed without creating a menace to life and property."

12. Weid Canyon Dam (re-named Mulholland Dam when it was dedicated in December of 1924), which had a very similar design to that of the St. Francis Dam, was modified by the placement of 330,000 cubic yards of fill against the downstream face of the dam. The added fill made it one of the most conservative dams in the state.

13. Birth of the compaction test. Bouquet Canyon Reservoir was the replacement structure for the St. Francis Reservoir built under the direction of Los Angeles resident field engineer Ralph R. Proctor. The dams consisted of two zoned fill embankments, which were constructed using Proctor's newly developed compaction test. The standard Proctor Compaction Test remains in use world-wide.

Back in Mississippi, engineers with the State Highway Department began to consider the geology of its bridge sites. On February 23, 1935, State Geologist Dr. William Clifford Morse accompanied State Highway Department engineers C. W. F. Harper, C. S. Hill, and W. Ellis York to inspect a proposed site for the Yazoo River bridge of U.S. Highway 49 West at Yazoo City (**Figure 545**). Morse noted that the Yazoo River was undercutting the site and had undercut it to such an extent that the bluff stood abruptly 245 feet above the floodplain of the river. The bluff in ascending order consisted of 131.7 feet of Yazoo Clay, 25.0 feet of pre-loess terrace sand and gravel, and 88.0 feet of loess. Morse found that the old city reservoir had been cracked and abandoned due to a slope failure at the site. The state geologist then documented recent landslides on two spur ridges at the proposed

Figure 546. Top, landslide that extended to the top of the first spur ridge (A) east of the Yazoo River. Bottom, the landslide embraced the whole vertical face of the east bluff of the Yazoo Valley on the west side of the first spur ridge (A); the camera is pointed North 22 degrees West toward the proposed bridge site. Pictures are from figures 5 (top) and 7 (bottom) of Mississippi Geological Survey Bulletin 27 (Morse, 1935).

Figure 547. Landslide during the winter of 1934-1935 near the line proposed for Highway 49 at the end of the second spur ridge (B) east of the Yazoo River. Pictures are from figures 2 (left) and 4 (right) of Mississippi Geological Survey Bulletin 27 (Morse, 1935).

Figure 548. Landslide scarp of loess at left against pre-loess sand and gravel at right along the bluff line on Old Highway 61 in Vicksburg, Mississippi. Picture was taken by James Starnes on April 8, 2013.

bridge site (**figures 546-547**) and steered the Highway Department to a better location labeled E-F in Figure 4, which is the location of the bridge today. In Mississippi Geological Survey Bulletin 27 entitled “Geologic Conditions Governing Sites of Bridges and Other Structures,” Morse said (Introduction, page 7) that his condemnation of the site saved the state perhaps $100,000 ($250,000 if the cost of the whole bridge project is included), an amount equivalent to the State Geological Survey’s appropriation in 15 years.

Another cooperative effort occurred after landslides in the winter and spring of 1946 destroyed the approach spans of the U.S. Highway 61 bridge over the Yazoo River at Redwood, Mississippi. In March of 1946, concerns over addition landslides led the Mississippi Highway department to contract with the Army Corps of Engineers drill crew and with Mississippi Geological Survey geologist Fred Mellen to check for faults at a new bridge site. Mellen examined drill cuttings and fossils and drafted a cross section, showing the location of the slide block and the location of solid ground, so that the bridge construction could avoid the failed surface. This story was published from an account given by Highway Department engineer George Lemon (who worked with Mellen on the bridge site) in the January 2004 issue of the Mississippi Geological Society Bulletin. Today MDOT has a registered profession geologist on staff to review all drill tests for bridge pilings. **Figure 533** shows the loess in two down-thrown blocks against pre-loess gravel in a dirt pit in the bluff line along Old Highway 61 in Vicksburg.

Figure 549. The roof tops of homes built below lake level in a subdivision in Clinton, Mississippi. Picture was taken on February 16, 2013.

Mississippi Dam Safety. The Dam Safety Division of MDEQ's Office of Land and Water Resources gives the following as its goal (MDEQ website):

"The goal of the Dam Safety Program is to protect people and property from the damaging consequences of catastrophic dam failures. Since 1960, in the United States there have been at least 25 dam failures that caused one of more fatalities. The worst of these failures, in terms of loss of life, was the 1972 failure of a privately-owned tallings dam in Buffalo Creek, West Virginia, which devastated a 16 -mile long valley with 6,000 ihhabitants. As a result of that failure, 125 people were killed and 3,000 were left homeless.

"Each year there are a number of dam failures in Mississippi and probably an equal number of dams that are breached under controlled conditions to avoid the possibility of a sudden failure. Some dam failures in the state have caused significant property damage, but there have been no fatalities in Mississippi attributed to a dam failure. Our goal is to provide sufficient oversight of the operational safety and structural integrity of dams in Mississippi to minimize the possibility of a life threatening catastrophic failure occurring at a dam that falls under our jurisdiction."

Though there have been no recorded fatalities due to a dam failure in Mississippi, the failure of the Big Bay Lake dam in Lamar County was a very close call.

Big Bay Dam Failure. Big Bay Lake in Lamar County, Mississippi, was 1,100 acre lake built to increase property values of lakeshore residences. The failure of the lake's

Figure 550. Satellite images of the Big Bay Dam before (top) and after (bottom) the failure. The scar left by the flood waters in clearly visible in the image below (from Altinakar, et al., 2010). Image 2398.

dam in March of 2004 made the list of the American Society of Civil Engineers, Report Card for America's Infrastructure of dams that "represented one of the greatest risks to public safety." The list included: (1) the 1889 failure of the South Fork Dam above Johnstown, Pennsylvania, (2) the 1928 California St. Francis Dam failure, (3) the 1972 Buffalo Creek Dam failure in West Virginia, (4) the 1976 Teton Dam failure in Idaho, (5) the 1977 Toccoa

Figure 551. Failure breach in the Big Bay Dam. Pictures were taken by the National Weather Service Forecast Office in Jackson, Mississippi, on March 16, 2014. Image 2399.

Figure 552. Damage caused the Big Bay Dam failure flood surge. Pictures were taken by the National Weather Service Forecast Office in Jackson, Mississippi, on March 16, 2014. Image 2400.

Figure 553. Left, Breached dam. Center, car washed into a tree. Right, Slab foundation of a home washed into the tree line. Pictures were taken on March 16, 2004. Image 2401.

Falls Dam failure in Georgia, (6) the 2003 Silver Lake Dam failure in Michigan, and (7) the 2004 Big Bay Lake Dam failure in Mississippi. According to Baker and Graham (2008, p. 10) the Big Bay Lake Dam failure was one of the largest volumes of water (22,100 acre-feet) released from a U.S. dam failure.

Big Bay Dam failed twelve years after its construction due to piping of water in the vicinity of its principal spillway. The dam was 1,890 feet long and 51.3 feet high and impounded a 900-acre lake. The breach began on Tuesday, March 11, 2004, with an increased discharge from a pre-existing seep. The seep gradually increased its discharge and contained sediment by the next morning on the 12th; by midmorning, it had a half-inch head height. The dam owner's engineer, noted the flowing water was clear of sediment. Due to poor cell phone coverage, the engineer had to leave the site to call a contractor to start work on the problem.

When conditions began to rapidly deteriorate, the engineer was called back to the site. Water shot out of the hole at 12:15 pm, spouting about 2 to 3 feet in height with a diameter of about 18 inches. At 12:20 pm, the area around the boil collapsed and the dam embankment began to erode rapidly. By 1:10 pm, the breach reached its full dimensions of 230 feet, with a top width of 315 feet (**figures 550-551**). The breach formation time was estimated from 12:20 pm to full formation at 1:15 pm, a duration of 55 minutes. Peak flow from the breach was estimated to be 147,000 cubic feet per second, as 6,180,072,500 cubic feet of water drained from the lake. The lake was completely drained within 90 minutes.

According to the National Weather Service Weather Forecast Office in Jackson, Mississippi, the dam failure damaged 104 structures, of which 48 were completely destroyed, 37 sustained major damage, and 19 sustained minor damage. In addition, 30 roads were damaged or closed because of the flood. The affected area stretched some 17 miles west of the dam, extending to where lower Little Creek meets the Pearl River. Flood waters were 15-20 feet deep where they crossed Columbia-Purvis Road. Here numerous trees were uprooted. Next, 10-15 feet deep flood waters washed out 75 yards of Tatum-Salt Dome Road. Here several homes were moved off their foundation and numerous automobiles were swept one fourth mile into the woods and lodged in trees (**figures 552-553**). Two mobile homes were moved and lodged against a tree line.

The hardest hit areas were along Robbins Road, which parallels Lower Little Creek for a little over a mile. Homes along this road were severely damaged or destroyed. Every home not attached to a concrete slab was moved off its foundation, and all automobiles were swept one fourth mile from their original position. Where Robbins Road met with Caney Church Road, a section of the road was washed out. Next a small section of Luther-Saucier Road was washed out. West of Luther -Saucier Road at McGraw Road, the flood waters were five feet deep. Here three homes were moved off their foundation.

Flood waters slowed as they crossed into Marion County and were more confined to the creek channel. Several homes were flooded by 3-5 feet of water, and a few feet of water flowed over Highway 13. A large section of Pine Burr Road were it crossed the creek. Here large sections of asphalt were removed and placed neatly in residents' yards. The actual flood wave extended 19 miles down stream.

The decision to evacuate residents was made at 12:30 p.m. when the boil below the dam had grown to about 4 feet in diameter. By 12:35 p.m., EOC was directing a door to door evacuation and reverse call back to warn them of the breach. Around 12:40 p.m. the National Weather Service issued a flash flood warning for two downstream counties, and State Dam Safety was notified of a complete beach of the dam. Miraculously, there was no loss of life. This was due in part to circumstances that: (1) the breach occurred near noon on a weekday when most homeowners were at work, and (2) residents at home were successfully evacuated.

Dam Failures due to Hurricane Isaac. Hurricane Isaac made landfall on the Louisiana coast during the late evening hours of August 28, 2012, and again in the early morning hours of August 29, as a category 1 hurricane with sustained winds of 80 miles per hour (**Figure 554**). Damage was such in Louisiana's coastal marshes that some 20.6 tons of dead nutria were collected from the beaches of Hancock County, Mississippi, and just the first cleaning pass in September of 2012.

Isaac's near hurricane force wind gusts and heavy rains led to widespread power outages in Mississippi and Alabama; portions of Alabama recorded nearly a foot of precipitation. Many dams along the coastline were briefly over-topped, though did not completely fail and were later pumped to prevent failure. Overall, Isaac led to 41 fatalities and caused $2.39 billion in damages.

Lake Tangipahoa Dam Near Failure in Percy Quin State Park. The dam of Lake Tangiphoa is an embankment dam on the Tangipahoa River in Pike County, Mississippi. The dam was completed in 1940 and failed in 1942. It was rebuilt in 1945 as a cost of $75,000. The dam failed again in the spring flood of 1983, contributing to record floods on

Figure 554. Isaac as a Category 1 hurricane near the Louisiana coast on August 28, 2012. Image 2402

Figure 555. Mandatory evacuation area from Kentwood to Robert, Louisiana, due to threat of dam failure on Lake Tangipahoa in Pike County, Mississippi. (from Dan Swenson, The Times Picayune, on August 30, 2012). Image 2403.

the Tangipahoa River that stand today. The dam was rebuilt with a concrete flood control structure. Heavy rainfall from Hurricane Isaac on August 30, 2012 (**Figure 554**), caused a slope failure along two 100-foot-wide sections of the downstream side of the dam. This led to the evacuation of 60,000 people downstream of the dam over concerns of high reservoir levels and dam stability (**Figure 555**).

Lake Tangipahoa was schedule to be drained and the dam rebuilt before Hurricane Isaac. The dam was dilapidated and not condition to withstand a large rain event. Before Isasc made landfall, MDEQ geologist and dam safety engineer Mike Meadows called several dam sites of large reservoirs with the message to monitor the dam and call him if a problem developed. At about 6:45 a.m. on August 30, a call came in from Percy Quinn State Park — we have a problem. The park ranger had spotted a 70-foot wide landslide on Lake Tanipahoa's dam (**Figure 556**). The ranger then notified the local emergency manager and the National Weather Service.

Meadows and dam safety engineer Natalie Sigsby then drove to Pike County to inspect the dam. Before they arrived around 9:00 a.m., the National Weather Service in New Orleans warned of flash floods, after local emergency management and law enforcement officials reported that Lake Tangipahoa Dam was expected to fail. Upon receiving the warning, Louisiana Governor Bobby Jindal sent 200 buses to evacuate Tangipahoa Parish citizens. Meadows and Sigsby surveyed the 2,300-foot long, 25-foot high dam and concluded that all they could do was to monitor the situation. If the dam was going to breach, there was nothing that could be done at that moment to stop it.

MDEQ Director of Dam Safety, James MacLellan, reported that early signs suggested that the dam would hold. He said there was "still 50 feet of clay between the water and the slide."Col. Jeff Eckstein, commander of the Vicksburg District of the Army Corps of Engineers arrive in the afternoon and assessed the

Figure 556. One of two slope failures on the Lake Tangipahoa Dam. Water seeping over the dam's clay core can be seen at lower left. Picture was taken by Mike Meadows on August 30, 2012 at 9:19 a.m. Image 2404.

Figure 557. Firefighters pump water out of Lake Tangipahoa in an effort to relieve pressure on the dam. Picture was taken on August 30, 2012 (AP Photo/The Enterprise-Journal, Matt Williamson, published on August 31, 2012). Image 2405.

Figure 558. Flood waters flow over low spot on park road to Lake Tangipahoa Dam. Picture was taken by Mike Meadows on August 30, 2012, at 2:56 p.m. Image 2406.

Figure 559. Tractors pump water from Lake Tangipahoa to lower the lake level against a backdrop of storm clouds in the distance. Picture was taken by Mike Meadows on August 31, 2012, at 12:01 p.m. Image 2407.

real danger to come if the water overtopped the dam and washed away more of the earthen dam. The water was rising, but Eckstein could tell the dam was not about to fail.

The National Weather Service warned that a break in the Tangipahoa Lake Dam would raise the level of the already swollen Tangipahoa River from 11 to 17 feet in Kentwood, Louisiana. Tangipahoa Parish President Gordon Burgess issued an emergency alert warning of an "imminent failure" of the dam. Some 50,000 to 60,000 people had 90 minutes to evacuate. McComb Mayor Whitney Rawlings told CBS News that there was a "50-50 chance of the dam failing. Updates on the Tangipahoa Parish website between 8 a.m. and 1:00 p.m. give a picture of the changing information spread between the states. The first alert at 9:00 a.m., August 30, warned of "imminent failure." The second said that Mississippi's emergency management agency had notified the parish government that the dam "is failing." The third alert said that the dam "is damaged but has not failed."

MDEQ's MacLellan called the media reports an overreaction. He explained, "CNN was saying the dam had failed, and there was a huge wall of water heading to Louisiana. Next thing we knew, there was a helicopter from Louisiana flying overhead of the dam" (USA Today News, Updated September 13, 2012). Louisiana Governor Bobby Jindal told the media that the Louisiana National Guard helicop-

Figure 560. Green National Guard trackhoe at left and MDOT bulldozer, dump trucks, and personnel make the initial clearing and excavation to divert the lake water around the dam. Picture was taken by Mike Meadows on August 31, 2012, at 1:30 p.m. Image 2408.

Figure 561. MDOT crew and equipment work through the night on excavating the diversion canal. Picture was taken by Mike Meadows on August 31, 2012, at 8:37 p.m. Image 2409.

Figure 562. The diversion canal deepens as MDOT crews continue work around the clock. Picture was taken by Mike Meadows on September 5, 2012, at 9:13 p.m. Image 2411.

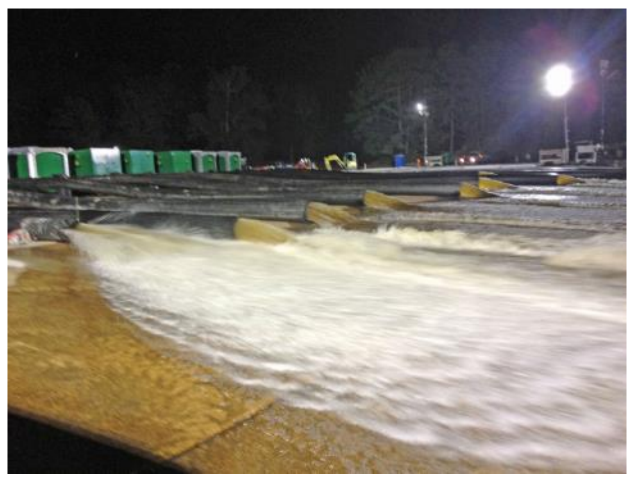


Figure 563. US Army Corps of Engineers 140,000 -gallon-per-minute pumps lower the lake level. Picture was taken by Mike Meadows on September 5, 2012, at 9:05 p.m. Image 2410.

ter was in the air to monitor the dam (arriving shortly before 11:00 a.m.). If the dam failed, it would take only 90 minutes for the water to reach Kentwood, Louisiana.

Mississippi Governor Bryant called the Mississippi Department of Transportation (MDOT) and the Mississippi National Guard to assist with the dam repair. Bryant announced in a news conference that officials were clearing an area to do a controlled breach of the 2,300-foot-long dam holding back the 700-acre lake.

The first relief came when Firefighters began pumping water out of Lake Tangipahoa on August 30 (**figures 557-559**). Louisiana National Guard helicopters placed boulders on the dam to ensure against failure, and the Mississippi National Guard arrived on site with bulldozers and trackhoes. The plan was to remove some of the roadway on the dam and allow some of the high water to flow into the fields, lowering the threat. The Nation Guard's equipment was relatively new but had seen little service. When put into operation, hydraulic lines on the heavy machinery gave way, each of which required a specified part. Soon well-used MDOT equipment and personnel took over the construction site.

Initially a Mississippi National Guard

Figure 564. Overflow at Lake Tangipahoa spillway on September 1, 2012. Excavation of diversion canal can be seen above the spillway road. Picture was taken by Mike Meadows. Image 2412.

Figure 565. The drained bottom of Tangipahoa Lake. Picture was taken by Mike Meadows on September 18, 2012. Image 2413.

Figure 566. Composite image of the dam landslide. The darker area in the middle of the slide is a seepage site from water moving over the dam's clay core. Picture was taken by Mike Meadows on September 18, 2012. Image 2414.

combat engineer unit (**Figure 560**) was dispatched to clear a forest and dig down through 30 feet of a hillside to excavate a 600-foot-long channel as a diversion around the dam for the flood waters. As mentioned before, this work was taken over by MDOT (**Figure 562-562**). When dam engineers decided to drop the water level in the lake at least eight feet to take pressure off the dam, the US Army Corps of Engineers brought in huge pumps capable of pumping 140,000 gallons a minute and dropping the lake level about a foot a day (**Figure 563**). Equipment and personnel from the Mississippi Department of Transportation took over the earthmoving job in the construction of the diversion canal (**Figure 564**) and worked through the night to complete the job.

On September 12, 2012, as the draining of Lake Tangipahoa was near completion (**Figure 565**), the body of a missing 18-year-old girl, Leslie Allen of McComb, was found on the lake bottom. Allen had been missing since September 4, and an autopsy showed no obvious signs of trauma. **Figures 566-567** show the failed dam slope, which consisted of unconsolidated sand and gravel. **Figures 568-569** show the diversion canal, with emptied into an older canal created for a pervious dam repair (**Figure 570**).

Lake Tangipahoa Dam was under reconstruction and the lake remained empty in early 2014, but by July 9, 2014, after strong spring rains, the lake was nearly full and was stocked with 250,000 mixed of red ear and blue gill; the following week the lake was stocked with bass. According to Jessica Bow-

Figure 567. Seepage site at dam landslide. The sand and gravel slope on both sides of the dam's clay core is fill from the Citronelle Formation, which covers nearly the whole surface of Pike County. Picture was taken by Mike Meadow on October 10, 2012. Image 2415.

Figure 568. Tangipahoa Lake's drain (Figure 520 shows other end of drain) stands high above the water in the nearly-drained lake. Behind it in the distance is the excavation of the diversion canal. Picture was taken by Mike Meadows on October 10, 2012. Image 2416.

Figure 569. A rip-rap on fabric lining was installed on the diversion canal to prevent soft sands of the Citronelle Formation from eroding. Picture was taken by Mike Meadow on October 10, 2012. Image 2417.

Figure 570. The end of the diversion canal led to an old canal used as a diversion from a previous lake repair. Picture was taken by Mike Meadows on October 10, 2012. Image 2418.

man of WLBT News (2014): "The 700 acre lake at Percy Quin State Park is full of water and now full of fish" (**Figure 571**). She interviewed park employee Jerry Brown, who said that the park received about 90 percent of its business from Louisiana, including Baton Rouge and the New Orleans area, and brought out-of-state dollars into southwestern Mississippi.

Figure 571. Lake Tangipahoa reopens for fishing. WLBT, September 13, 2016. Image 2538.

Figure 572. Areal view of Lake Serene in Hattiesburg, Mississippi, from Walker Associates in a Presentation to Homeowners Association. Image 2419.

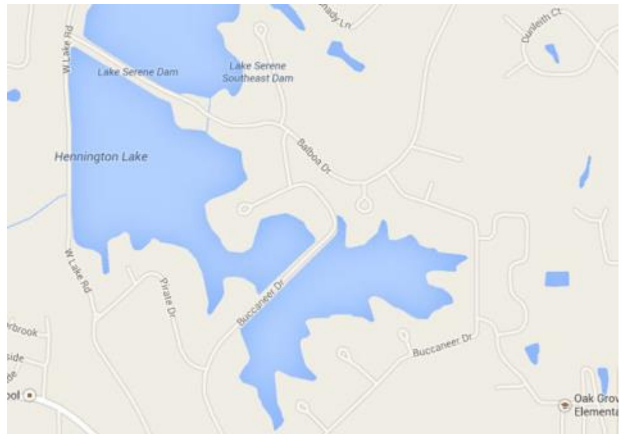


Figure 573. Google map of Lake Serene, showing Buccaneer Drive between lakes 5 and 6; the site of the dam failure. Image 2420.

Lake Serene failure in Hattiesburg, Mississippi. Hurricane Isaac also created a strong rain event at Hattiesburg, Mississippi, which caused a failure on the dam of Lake Serene—Lake #6 (**figures 572-573**). Heavy rains saturated the earthen barrier between Oak Grove and Stump lakes, causing a 100-yard section of the downstream embankment to slump (**Figure 574**). The slump also produced a jagged crack in the asphalt of Buccaneer Drive. Some residents below the dam were evacuated, having a short time to retrieve their valuables. To prevent the dam from breaching, water levels in the lakes were lowered, and Bucaneer Drive was closed.

Lake Serene #6 Dam was built in 1969 at a length of 1,912 feet and a height of 24 feet with a normal lake surface area of 68.5 acres. The lower level outlet consisted of a 24-inch-diameter metal pipe. The principal spillway was 50 feet in width; there was no emergency spillway. The dam's hazard classification was High.

Dams built before 1982 were required a probable maximum precipitation (PMP) ourfall structures to pass 15.5-inch rainfall event in 24 hours. Today's standard requires PMP outfall structures to pass a 46.8-inch rainfall event in 24 hours. The contracted engineering firm recommended both the upstream and downstream faces of the dam be flattened to a 3:1 slope and a video inspection of the low level conduit to determine if repairs were needed. It was also recommended that a request be made to MDEQ that the dam be "granfathered in" the dam repairs to pre-1982 criteria. The overall estimated cost of repairs was $3,250,000.

Figure 574. Slope failure on Lake Serene slope and road, from Walker Associates in a Presentation to Homeowners Association. Image 2421.

The estimated cost near the time of final construction plans was placed at $1,65 million and required an assessment of $2,921. Repair of the dam's downstream slope required benching of fill, beginning at the base of the dam and creating a terraced appearance as the work continued toward the top (Doherty, Hattiesburg American, 2014).

Figure 575. Water overtopping dam in Rankin County during storm event that was greater than the spillway design. Image 2422.

DESIGNING FOR THE FLOOD

Dams and Extreme Weather Events

By James MacLellan, Dam Safety Division, Office of Land and Water Resources

The following is from the November 2009 issue of *Environmental News*, pages 3-4. All too often, we in the Dam Safety Division get responses of shock and disbelief when we tell people what storm event high hazard dams must be designed to handle. High hazard dams are dams which, if they were to fail, are likely to cause loss of life and destruction or serious damage to residences, commercial buildings or industries (**Figure 575**). Therefore, these dams are required to safely pass and/or store the runoff from a design storm known as the Probable Maximum Precipitation (PMP) without overtopping the dam. When we tell people what the PMP is, their response is usually, "That's impossible," or "It has never rained that much in my lifetime," or the most startling response that I've heard was, "That is a Noah flood, and that can't happen again."

The PMP is a design storm event that has been modeled by the National Weather Service in order to determine the worst case storm that could happen. That is where it gets its name of probable maximum precipitation. The National Weather Service modeled PMP events for different lengths of time (duration) such as the 6 hour storm, the 12 hour storm and the 24 hour storm. The 24 hour PMP for Mississippi ranges from 40 inches of rainfall in the north part of the state to 48 inches of rainfall along the Coast. That is why we are usually hear statements of disbelief when we mention this particular design standard.

The Dam Safety Division is responsible for assuring that dams in Mississippi are constructed and maintained in such a manner as to provide adequate safety for downstream lives and property. Almost half of earthen dams that have failed, failed due to being overtopped because their spillway(s) and storage capacity were too small to handle that big storm that

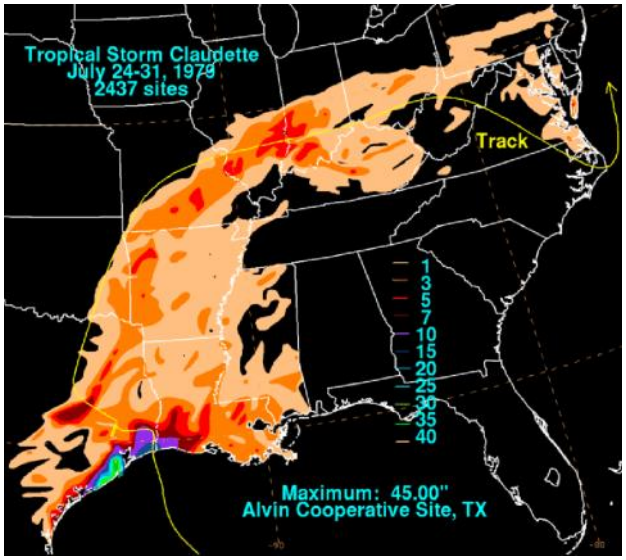


Figure 576. Tropical Storm Claudette rainfall graphic. Image 2423.

overwhelmed them. The one that their designers said: "That's impossible."

As in other fields of engineering, dam engineering has learned from past failures and has developed design standards, much like building codes, to assure that safer dams are being built today. Just as in designing buildings or bridges, dams are designed not only for their expected loading but also for extreme loads plus a safety factor. Design storm events like the PMP are used so that there is a safety factor. You don't design a dam just for the storms that you have seen, but rather you design it for some extreme storm event so that it will handle all the storms that you expect to see, and ones that you never expected. Designing adequate spillway capacity (the amount of flow the spillway can carry) and excess storage capacity (the amount of water that can be stored above the normal lake level and below the top of the dam) is one of the critical components in safe dam design.

Unfortunately these extreme storms, while rare, do occur. When dealing with flood producing events, it is not only the amount of rainfall that must be considered but also the duration and the intensity (measured in inches/hour). A storm where 10 inches of rain falls in 5 hours will produce more flooding than 30 inches of rain falling over a month. This is because the intensity of the first storm is greater than the second storm and rain is falling faster than the water can drain off. A 24 hour PMP design storm of 40 inches would have an average intensity of 1.67 inches per hour. So, when a storm hit the Florence / Richland area in August, 2001, and 10 inches of rain fell in 6 hours, the intensity of that storm was the same intensity as the 24 hour PMP design storm of 40 inches. I live in the Florence / Richland area and remember that storm as small creeks overtopped bridges that had never overtopped before (that people could remember), and as a section of Highway 49 through Florence flooded and had to be closed. The most intense storm event recorded for Mississippi occurred near Purvis in Lamar County on October 23, 1991. During that storm ***7 inches of rain fell in 1 hour***, which is a higher intensity than the 24 hour PMP design storm average intensity. Other extreme storm events include Hurricane George in 1998 where rainfall amounts in excess of 20 to possibly 30 inches along portions of the Gulf Coast were reported, and Hurricane Camille in 1969, which stalled over West Virginia and rainfall amounts there exceeded 30 inches in 24 hours. In 1947, 12 inches of rainfall fell in 42 minutes near Holt, Missouri, 22 inches of rainfall fell in 2.75 hours near D'Hanis, Texas, in 1935, and 30.8 inches of rainfall fell in 4.5 hours near Smethport, Pennsylvania, in 1942.

One actual storm event that closely matches the 24 hour PMP design storm occurred in 1979, near Houston, Texas, when tropical storm Claudette stalled over the area. The town of Alvin recorded ***42 inches of rainfall in 24 hours***. Alvin is located in the greater Houston metropolitan area (**Figure 576**). Pat Mason, who now works in our agency, was working on an oil rig near there during that time and remembers that storm well. I talked to her about the experience, and she told me about how the crew kept going out to keep the rig running during the storm, but that there were times when all they could do was to huddle in the trailers because the rain was coming down so hard. She said that the entire county was flooded and stayed flooded for several days.

The 24 hour PMP design storm as modeled by the National Weather Service is the best, practical design standard that we have. This is the standard that is used by most of the dam safety agencies in the country. Using this standard gives a safety factor for dams to handle short, intense storms as well as prolonged, low intensity storms such as the ones that produced flooding around the Atlanta area this past September. While any of the events described above will produce destructive, even catastrophic flooding, the Dam Safety Division uses a safety standard to assure that the destruction and possible loss of life won't be added to by the failure of dams.

DAM SAFETY DIVISION WHITE PAPER

The following was published under the title of “Dam Safety Division—protecting people and property” in the March 2014 issue of *Environmental News*, much of it written by Dusty Myers.

A series of catastrophic dam failures across the country in the 1970s, which caused the loss of hundreds of lives and over a billion dollars of property damage, led to the issuing of a Presidential Executive Order in 1977 requiring the U.S. Army Corps of Engineers to inspect the nation’s non-federal high hazard dams. The Corps of Engineers coordinated with the states to inventory all dams in each state and to inspect the ones that the states believed threatened downstream lives and property. The inspection reports were then given to the states for them to take action.

In 1978, the Mississippi Legislature authorized the Mississippi Board of Water Commissioners (which would later become the Office of Land and Water Resources of the Mississippi Department of Environmental Quality) to launch a dam safety program to ensure that dams are built and maintained properly to protect downstream lives and property.

State law has given our agency the responsibility to implement and enforce dam safety laws and regulations, but it is so much more than that. It's about protecting people, their homes and their livelihoods, along with vital infrastructure like roads and bridges. It’s about being prepared and preventing problems before they happen and also responding quickly and efficiently if there is a dam failure,” said Trudy Fisher, MDEQ Executive Director.

The Dam Safety Division’s primary duties are to:

- ●Enforce the state’s Dam Safety Statutes and Regulations.
- ●Review the design plans and specifications for all dams constructed in the state greater than eight feet in height or store more than twenty-five acre-feet.
- ●Inspect dams and review dam inspection reports.
- ●Provide information and educational outreach to dam owners and the general public.
- ●Oversee the development of emergency action plans for high hazard dams and ensure the plans are reviewed and updated.
- ●Maintain a database and files on all dams in the state.
- ●Respond to dam incidents and failures.

In addition, Dam Safety staff is working to identify dams that have been constructed in the past 30 plus years without authorization. Preliminary results show that there may be an additional 3,100 dams that will meet the criteria to be added to the state’s inventory.

Each year in Mississippi there are several dam failures with the most notable being Big Bay Dam in Lamar County which failed in 2004 damaging or destroying more than 100 homes but thankfully not causing any loss of life. Another serious incident the state has faced in the past few years was the Percy Quin State Park dam incident in Pike County in 2012 where a failure of the dam could have potentially threatened not only Mississippi residents but also people downstream in Louisiana. The MDEQ Dam Safety Division, along with several state agencies, responded to the incident and was able to prevent the failure of the dam.

It is the Dam Safety Division’s role to ensure citizens’ lives and property are protected from dam failures through a proactive system of inspections and assessments that identify and address deficiencies in dam design and construction prior to failure. Staff also works to prevent the loss of lives and property by responding to incidents at dams to prevent failures so the effects are as minimal as possible.

CHAPTER 13. SALT DOMES

TATUM SALT DOME NUCLEAR SITE

Satirist and writer of the comic strip Li'l Abner, Al Capp, created a script for a Broadway musical that opened in 1956, and later a musical film released in 1959, entitled "Li'l Abner." In the musical, Li'l Abner's hometown of Dagpatch, U.S.A., found that they had been selected as the "most unnecessary place in the county" and that their town would become a nuclear test site. The search for such a place was prompted when wealthy gambles in Las Vegas grew weary of atomic explosions at the nearby Nevada test site. Citizens of Dogpatch were initially please to move but changed their minds when Mammy Yokum explained to them the horrible customs of the outside world, such as bathing and working for a living.

Now the people of Dogpatch were in a desperate search for something necessary about their town. Not long after release of the Li'l Abner movie by Paramount Pictures on December 11, 1959, a place in southwestern Lamar County, Mississippi, became Dogpatch—"the most unnecessary place in the county" with its selection for the first nuclear explosion in the lower 48 states outside of the Nevada test site.

October 22, 2014, was the fiftieth anniversary of the first and only nuclear blast on US soil east of the Mississippi River at Tatum Salt Dome in Lamar County, Mississippi (**figures 577-580**). Louisiana State University Press released a new book on the subject by D. A. Burke in November of 2012. This book did not address the role of the Mississippi Office of Geology in drilling observation wells at the site as given below, but did detail the work of former State Geologist Fed Mellen in his efforts to prevent a nuclear detonation in Mississippi, fearing adverse consequences for the future development of natural resources at the site.

Figure 577. Location of salt domes in Mississippi with Tatum Salt Dome identified. Image 2424.

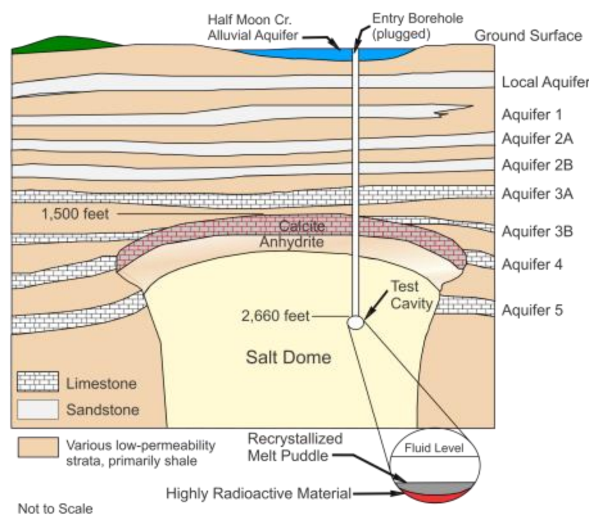


Figure 578. Diagrammatic cross section of Tatum Salt Dome with overlying and flanking aquifers identified. Image is from the U.S. Department of Energy, Fact Sheet, Salmon, Mississippi, site; the blast cavity is not to scale. Image 2425.

This detonation, known as the Salmon nuclear event, was the only nuclear test site east of the Mississippi River, the first nuclear blast in a salt dome, and only the third underground nuclear blast outside of the Nevada Test Site. To date only five U.S. states have had nuclear test sites: Mississippi, Nevada, Alaska, Colorado, and New Mexico. Three additional explosions, two chemical and one nuclear, were detonated within the initial Tatum Dome blast cavity (Johnson and Harrelson, 1981). The second nuclear event was know as the Sterling Event and took place on December 3, 1966. The United States Department of Energy transferred the Salmon Site, a 1,470-acre tract of land, back to the State of Mississippi on December 15, 2010 (Blount, Clarion-Ledger,, p 10B).

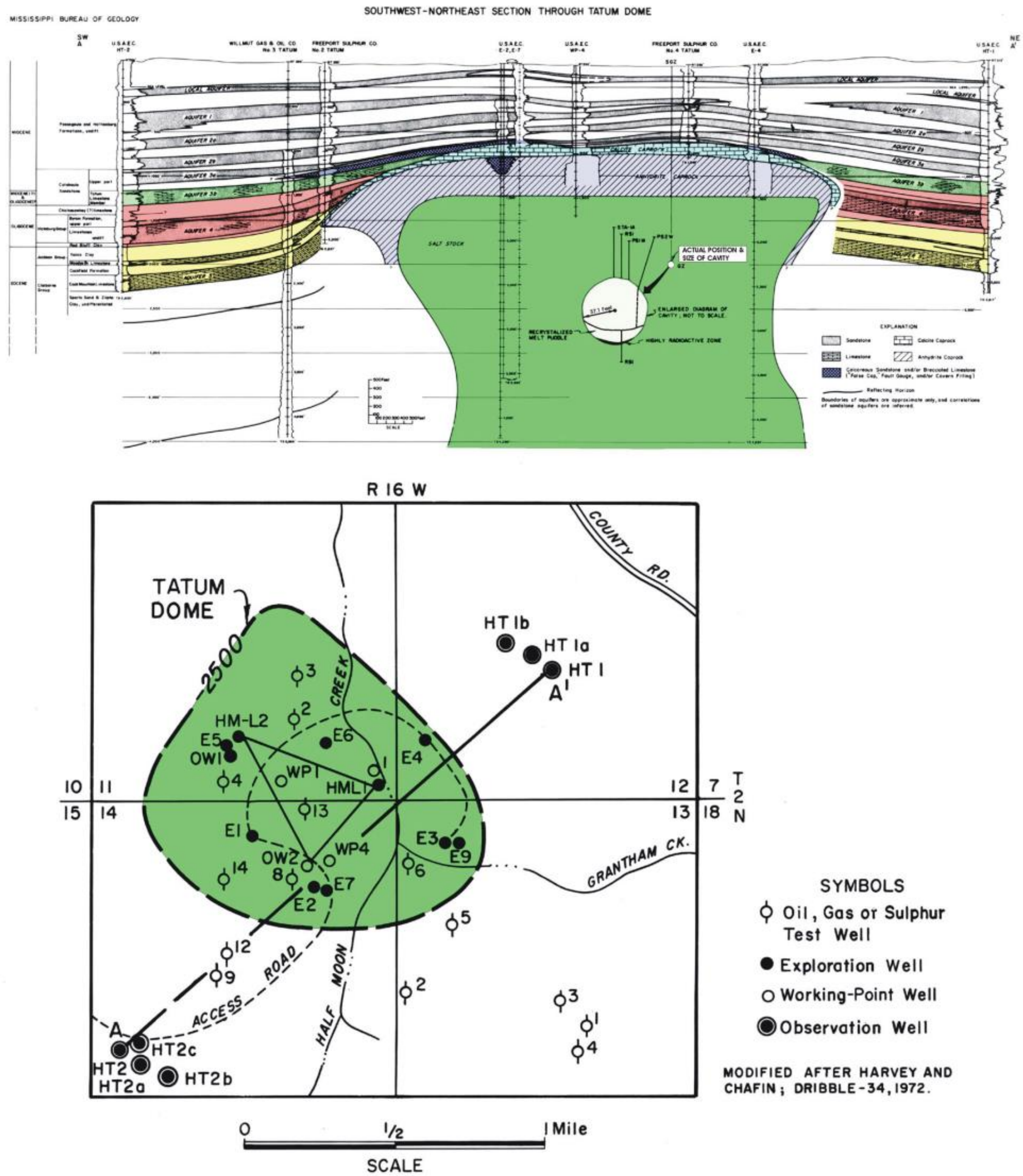


Figure 579. Top: Cross section A-A' across the Tatum Salt Dome nuclear site in Lamar County, Mississippi, showing the blast cavity at scale and enlarged. Bottom: Location map of the salt dome perimeter at –2,500 feet, line of section, and observation wells OW1 and OW2 and monitor well HM-L2 (from Johnson and Harrelson, *Mississippi Geology*, December 1981, p. 10). Image 2426.

Some 400 hundred residents of nearby Baxterville were evacuated before the Salmon nuclear event. Even after evacuation, they experienced a shock greater than expected, and returned to find their homes damaged (over four hundred claims were filled with the government to recover loses. The blast was described as a muffled detonation that "set off a

580. Salt core from Tatum Salt Dome. Image 815.

land wave that looked like a three-foot high tidal wave across much of the county. The wave upended recording instruments, cracked homes and jolted news reporters stationed at an outpost 1½ miles away" (Ourlian, *Clarion-Ledger*, June 29, 1984, p. 1A). Former dome site security guard Junior Nobles recounted, "I was stationed at a metal building with some other guards about a mile and a half away, and that building shook. We had to catch one of the men because he was running around the outside of that building yelling, 'We're dead, we're dead." Another guard at that building told his wife Bernice Roseberry that "the ground came up almost to his knees, three times" (Spear, *Clarion-Ledger*, October 22, 1989, p. 17A).

Kevin Saul was seven years old when the blast occurred. His family home was about half a mile from ground zero; they evacuated to his grandparent's home some one and a half miles away. He recounted that the house shook like an "earthquake came through" and that the ground "had a buckle effect to it. It would knock you off your feet." When his family returned home, they found the chimney moved out from the house, the house and outhouse

Figure 581. Media at the official observation point approximately 3.5 mile southwest of ground zero at Tatum Salt Dome nuclear test at 10:000 a.m. on October 22, 1964. Item #208 of the MDAH Moncrief Photograph Collection. Image 2427.

moved off their foundations, lots of windows broken, and the water well caved in (LaRecca Rucker, *Clarion-Ledger*, January 28, 2013, p. 1A, 3A). Award-winning Hattiesburg newspaper photographer Winfred Moncrief photographed events around the blast site on October 22, 1964, and at the time of an earlier postponed blast date on October 9, 1964. He donated these photographs and others from 1952 to 1968 to the Mississippi Department of Archives and History in 1994. The collection was made available on line in 2007 (*Mississippi History*, October 2007, p. 1) (**figures 581-583**).

Buildings swayed for "several minutes" in Hattiesburg. The effects of this shaking were later blamed in part for the collapse of a ceiling on 30 students (seven of which required hospitalization) in a University of Southern Mississippi class room on February 21, 1984

Figure 582. Seismograph before blast (left) and toppled after blast (right) at Tatum Salt Dome nuclear test site official observation point, respectively, before and after 10:00 a.m. on October 22, 1964. Items #240 (left) and #250 (right) of the MDAH Moncrief Photograph Collection. Image 2428.

Figure 583. Bracing a chimney before the blast (left), and the ransacked home of Horace Burge, located about two miles from ground zero, after the blast at Tatum Salt Dome on October 22, 1964. Items # 194 (left) and #260 (right) of MDAH Moncrief Photograph Collection. Image 2429.

(Wells, *Clarion-Ledger*, April 4, 1984, p. 1B). Will Lowery (personal communication) was staying in the one-story Holiday Inn in Hattiesburg when the blast occurred in the early morning hours. The building shook so strongly that guests fled their rooms in their sleepwear and underclothes and ran into the street. Water in local creeks turned dark from silt that was freed by the shock. Two months later, researchers drilled a hole into the blast cavity to measure radioactivity. While drilling, some radioactive water and soil surface, prompting a government effort to clean up the site. In the years that followed, residents complained of health issue they believed to be related to radiation from the blast site. Around 2000, the government built a water pipeline to supply resident with groundwater from a distant source to alleviate some of their concerns.

In 1979, Dr. Edmund Keiser, Chairman of the Biology Department at the University of Mississippi, reported fish, tadpole, and toads at the test site to show high levels of tritium, a low-level radioisotope left behind after the government's cleanup of the area. Six contaminated toads at Tatum also had deformed toes or skin damage (Kubissa, *Clarion-Ledger*, April 6, 1979). Kieser later found the liver of one green frog from the site to be contaminated with the radioisotope sodium-22 at 1,000 times the amount of radiation that would normally be present. Kieser determined that the frog had come in contact with the radiation in a mater of weeks. The find was reported to the governor's office with the recommendation of closing the area to the public. Ron Lewis, Chairman of the Mississippi Sierra Club, stated that Kieser told him that the contaminated frog liver "will cause a Geiger counter to go off scale." Lewis made his own press announcement, "I am calling for an immediate closing of all access in the salt dome in Lamar County because of the overwhelming evidence that the atomic blasts set off during the 1960s have left the area highly contaminated with radiation."

Governor Finch ordered an evacuation of the 1,400 acre site, which was enforced by sheriff deputies, who roused about fifteen families out of their homes in the early morning darkness of Friday, May 25, 1979 (Harrist, *Times Picayune*, May 26, 1979). Half the families returned to their home that same day after the governor determined they were not in any immediate danger. A political cartoon in the May 29, 1979, issue of the *Clarion Ledger* showed Ole Miss two professors perched above a pond labeled "Tatum Salt Dome" looking through binoculars and declaring "It looks all clear to me!"—their perch was actually the head of a Gonzilla-sized frog.

At the time the report of Sodium-22 in a frog's liver was released, University of Mississippi spokesman Dr. Ed Meek noted to the press that Sodium-22 was not a normal product of nuclear fission (Associated Press, Clarion-Ledger, May 25, 1979, p. 3A-4A). Ed Meek would later report that a contaminated laboratory oven, which contaminated a dish, at the University of Mississippi, was responsible for the high sodium-22 readings (Associated Press, Clarion-Ledger, May 30, 1979, p. 13A; Associated Press, Clarion-Ledger, June 7, 1979, p. 8B). Kieser acknowledged this and apologized to the displaced residents (Dougherty, 2010, p. 208). Though proven false, this incident was cited by the authors of *Killing Our Own*.

A report of new studies on radioactive elements at the Tatum site was release on November 28, 1979, to the Governor's Select Committee on Nuclear Energy and Nuclear Waste Repositories. As detailed by Mark Schleifstein (Clarion-Ledger, November 29, 1979, p. 3A), "New studies at Tatum Dome in Lamar County have turned up radioactive elements that may be more dangerous than those already discovered at the site, a State Board of Health official said Wednesday." The source of the new elements was soon found to be from the components of a heavy drilling mud used at the site called ferrochromic lignous-sulfate. This mud contained lignite, which has naturally occurring radioactive materials, including radium and thorium. The special drilling mud was used to seal off groundwater while drilling through the salt dome's porous caprock (Schleifstein, Clarion-Ledger, November 30, 1979, p. 3A).

About 200 feet of 5-inch diameter salt cores, obtained by the Federal Government from Tatum Dome before the Salmon event, were stored at the Office of Geology for a time before they were disposed of for lack of space. A few samples of these cores were saved such as the core shown in Figure X. This figure illustrates the coarsely crystalline texture of the rock salt that characterized the entire 200-foot core interval.

Saunders (1989) gave a cross section illustrating the aquifers adjacent to and overlying Tatum Dome and discussed the site history and aquifer chemistry. The Cockfield aquifer (aquifer 5) was the lowest aquifer of his study and had saline water. The Vicksburg aquifer (aquifer 4) was backish and, along with aquifer 5, was truncated along the dome's flanks. The Catahoula aquifers 3B and 3A covered in part (3B) and completely (3A) the crest of the dome. Aquifer 3A had a higher temperature over the dome at 34° than away from the dome at 29°, reflecting the typical thermal anomaly associated with the high heat flow found in salt domes.

The Mississippi Bureau of Geology made plans in 1980 to test the groundwater around Tatum Dome to check for radioactive contamination. These plans were stymied by the legitimate concerns of landowners over the liability of state workers at the dome. They wanted to know who would be responsible if an accident occurred at the site (Associated Press, Clarion-Ledger, July 16, 1980, p. 6A). When liability issues were resolved drilling on the dome began in March of 1981. The March 26, 1981, issue of the Lamar County Head Block (Lowery, 1981) showed a picture of the state drilling rig and crew in action. Newly drilled wells were made to test the local aquifer for tritium contamination and to determine the rate and flow direction of water in the aquifer. Test results of wells in the local aquifer released by the State Board of Health concluded that the tritium in the local aquifer, the aquifer nearest the surface, was decreasing and the dome posed no health hazard (Lowery, Lamar County Head Block, July 9, 1981). Mississippi Office of Geology, Open-File Report OF-4 by Stover, Harrelson, and Johnson (1981) details the monitor well construction and hydrological testing at Tatum Dome.

In 1989, Senator Trent Lott asked the Department of Energy to study cancer rates near the Tatum Salt Dome after receiving a petition signed by 700 residents of the area. Some 66 residents died of cancer since 1966 and 22 were currently suffering from the disease. One of the deceased cancer patients was long-time site guard and husband of Bernice Roseberry, who gave the blast account above. Officials said that it would be the first DOE epidemiological study of people who simply live near a nuclear test site (Booster, Lumberton, Mississippi, November 2, 1989, p. 1, 3). A DOE spokesman said that a meaningful statistical study would require about 100,000 people. A community of about 1,000, like that of Baxterville, would not render between cancer victim and what caused the diseases.

In response to Lott's request, scientist from EPA and DOE arrived at the Tatum Dome site in April of 1990 to begin the most intensive investigation of the region that they have performed. They tested vegetables, residential water wells, venison, wood, frogs, snakes, catfish, creek water, and soil from the test site. Of the 25 residential wells tested none had tritium levels higher than 500 picocuries per liter. They also found that tritium in the salt-brine aquifer near ground zero had fallen from 450,000 picocuries in 1978 to between 9,000 and 10,000 picocuries. An epidemiological study was released on May 11, 1995, before an audience of about 100 people gathered at the Bay Creek Fire Station at Baxterville. Of 2,185 deaths in Lamar County between 1980 and 1991, 562 were cancer-related, a rate no different than that for the state at large (Walton, *Clarion-Ledger*, May 12, 1995). Thus, living around Tatum Salt Dome did not increase anyone's likelihood of getting cancer.

Richton Salt Dome. The National Academy of Sciences (NAS) recommended salt as a potential host rock for geologic disposal of radioactive waste in the mid-1950s. For nearly two decades before the Department of Energy was formed in October 1977, salt formations were the single-minded focus as host rocks for a high-level nuclear waste repository (Alley and Alley, 2013). Outside the agency, the wisdom of using salt formations for a repository was questioned by some scientists. A test program at Lyons, Kansas, demonstrated that the small brine-filled cavities in salt tended to migrate toward the heat source associated with nuclear wastes. A solution to this was a steel sleeve around the waste packages to prevent brine corrosion. The American Physical Society established a study group that recommended that not just salt by other geologic media such as granite and shale should be examined as a repository host as well.

As the selection of a national nuclear waste site dragged on, California initiated a moratorium on building new nuclear power plants until the state energy commission could certify a federally approved method for permanent disposal of spent nuclear fuel. This moratorium was stuck down by the courts but was upheld upon appear to the U.S. Supreme Court and still stands today. Connecticut, Wisconsin, and other states soon followed California's example. Retrievability of nuclear waste packages became an issue when President Carter decided in April 1977 to ban reprocessing of high -level waste. One of salts positive features for a repository was that it creeps and closes up openings, thus isolating the nuclear waste. However, this self–sealing property negates future retrievablility. Due to the disarray concerning nuclear waste policy in his administration, Carter formed a high-level Interagency Review Group (IRG) on Nuclear Waste Management. When IRG released their report in March 1979, key disagreements remained, and DOE continued to favor salt as the host rock.

The controversies concerning nuclear waste policy were complicated by the Three Mile Island accident in March of 1979 and the Iranian hostage crisis beginning in November

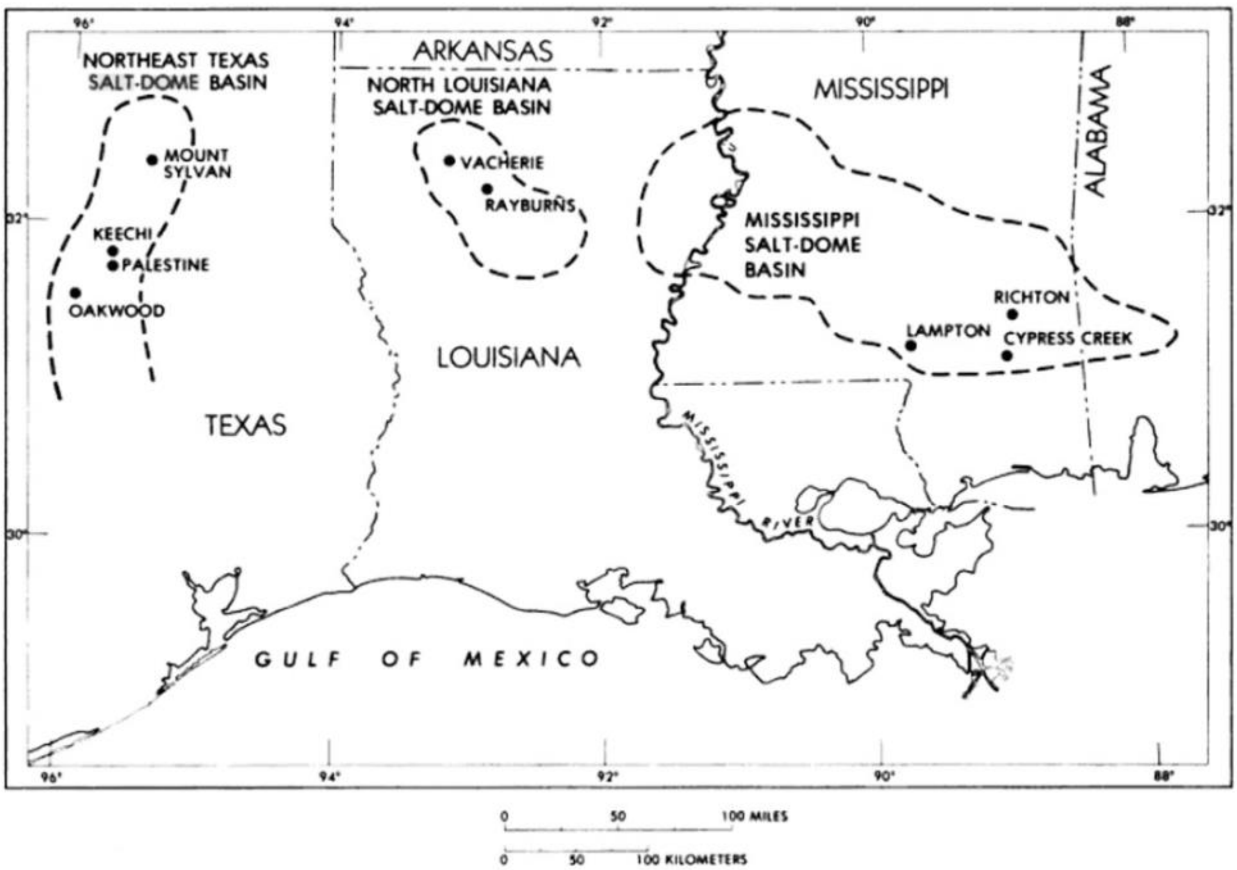


Figure 584. Gulf Coast area showing locations of salt domes being studies (U.S. Geological Survey, Circular 847, p. 29). Image 2435.

of 1979, which delayed Carter's final policy statement by almost a year. In the resulting vacuum, Louisiana's Democratic Senator Bennett Johnston, who was on the Committee on Energy and Natural Resources, sponsored a bill requiring that spent fuel be stored indefinitely in retrievable surface storage facilities. This was a convenient way of keeping a geological repository away from Louisiana salt domes. The Nevada Test Site was Senator Johnston's choice for long-term storage.

The U.S. Senate passed a nuclear waste bill on April 29, 1982, with little fuss and a vote of 69 to 9. The bill emphasized interim storage, restrictions on environmental assessments, and an accelerated schedule for siting and licensing. One important feature of the bill was a provision for a Nuclear Waste Fund financed by a fee on the utilities of 0.1 cent per kilowatt-hour of nuclear-generated electricity. The fund held the possibility of a handsome reward to the host state. In return for the fee, DOE signed binding contracts with the utilities to take legal charge of the spent fuel by January 31, 1998. President Reagan declared the passage of this bill as mission accomplished toward a safe and effective solution to the nuclear waste problem.

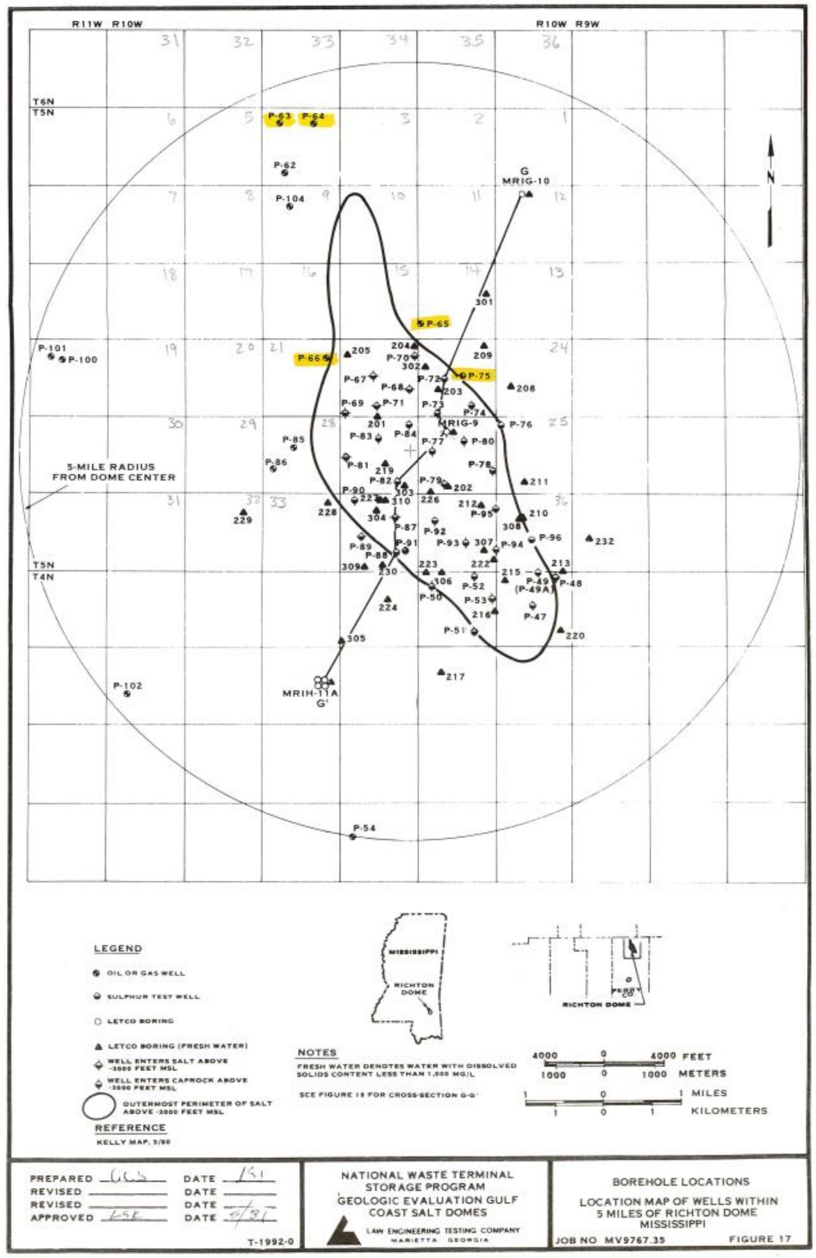


Figure 585. Map view of Richton Salt Dome outlined at the outermost perimeter of salt above –3,000 feet mean sea level and showing the location of boreholes, including oil and gas wells, sulfur test wells, and LETCO borings; grid in sections with some sections hand numbered (from Simcox and Wampler, August 1982, Borehole locations on seven interior salt domes: ONWI-280, Battelle Project Management Division, 102 pages). Image 2436.

The Nuclear Waste Policy Act required that a geologic repository be established in a few short years or else DOE could be besieged with lawsuits. This meant that the nine sites already under consideration would form the sole basis for those to be screened for the first repository. By 1984, these were narrowed to five states, three in salt formations, including a salt dome in Mississippi and bedded salt in Deaf Smith, Texas, and Davis Canyon, Utah, one in basalt in Hanford, Washington, and one in the volcanic tuff of Yucca Mountain at the Nevada Test Site. None of the five sites were perfect candidates. The Hanford site was associated with the Columbia Plateau aquifer and was not far from the Columbia River, the Nevada site was tectonically active, and Mississippi's salt dome site was more complex than salt in salt beds. Also, Richton Salt Dome (**figures 584-589)** was close to a town of 1,000 people. Senator Trent Lott of Mississippi, regularly argued for a "Richton amendment" that would eliminate any site exceeding a certain popula-

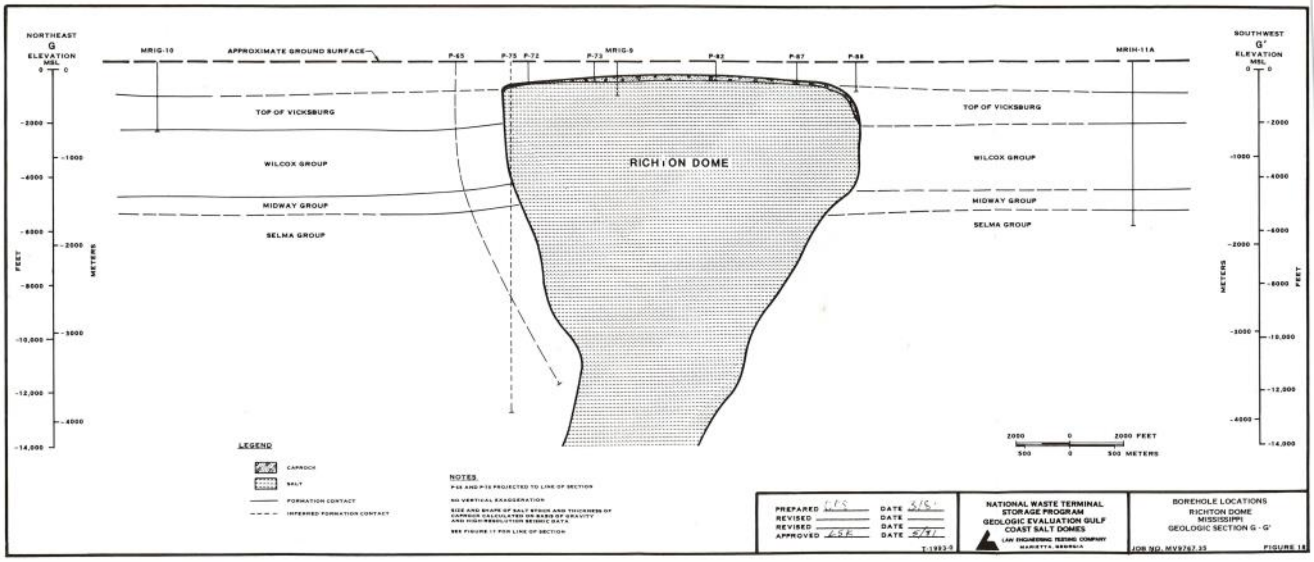


Figure 586. Northeast-southwest Cross Section G-G' of Richton Salt Dome, showing, in ascending order, the Selma Group, Midway Group, Wilcox Group, Claiborne-Jackson-Vicksburg groups, and unlabeled Miocene section (from Simcox and Wampler, August 1982, Borehole locations on seven interior salt domes: ONWI-280, Battelle Project Management Division, 102 pages). Image 2437.

tion density (namely the community of Richton).

The Perry County Citizens Against Nuclear Disposal, Inc. (PCCAND), was formed on November 6, 1981, after both Richton and Cypress Creek salt domes in Perry County were placed under consideration by the U. S. Department of Energy as nuclear waste repositories in early 1980. The organization battled proponents until 1988 when the Perry County sites were dropped from consideration; the organization disbanded in 1990. It was over these years that the Mississippi Bureau of Geology's Environmental Geology Division, headed by John Green and later Curtis Stover, spent considerable time reviewing and commenting on Department of Energy documents concerning Richton Dome and the selection of a national nuclear waste repository. PCCAND documents at The University of Southern Mississippi contain a file (Folder 6) with the correspondence between John Green and the Department of Energy from 1981-1985.

The Department of Energy contracted with the Office of Nuclear Waste Isolation (ONWI) of Battelle Memorial Institute to evaluate potential nuclear waste repository sites. Battelle is a charitable trust organized as a nonprofit corporation in the State of Ohio and traces its origins to the 1923 will of Ohio industrialist Gordon Battelle, which provided for its creation. The Institute originally focused on contract research and development of metals and material science. Now it is an international science and technology enterprise that explores emerging areas of science and manages laboratories.

The U.S. Geological Survey was involved with ONWI investigations including the Paradox Basin, Utah; the Gulf Coast saltsome region; and the Salina Basin, New York and Ohio (Schneider et al., 1982). Studies in Mississippi in 1979 found fresh water at depths greater than 900 meters (2,953 feet) in the Wilcox Group near Cyprus Creek Salt Dome (Gandi and Spiers, 1980). Data suggested the regional direction of groundwater flow was south to southwest at an average rate of 30 meters per year.

The Nuclear Waste Police Act in 1982 established the Office of Civilian Radioactive Waste Management (OCRWM) and charged it with the task of locating a suitable site where nuclear waste could be buried underground in the United State safely for 10,000 years. The office selected nine sites (including Richton Salt Dome) and evaluated them in a 1985 report. Based on this report, the original nine sites were reduced to just three—all in the West—including Hanford, Washington, Deaf Smith County, Texas, and Yucca Mountain, Nevada. Congress amended the Nuclear Waste Policy Act and directed DOE to study only one site, Yucca Mountain in Nye County, Nevada. This site was studied though the 1990s and was found to be ideal because of its

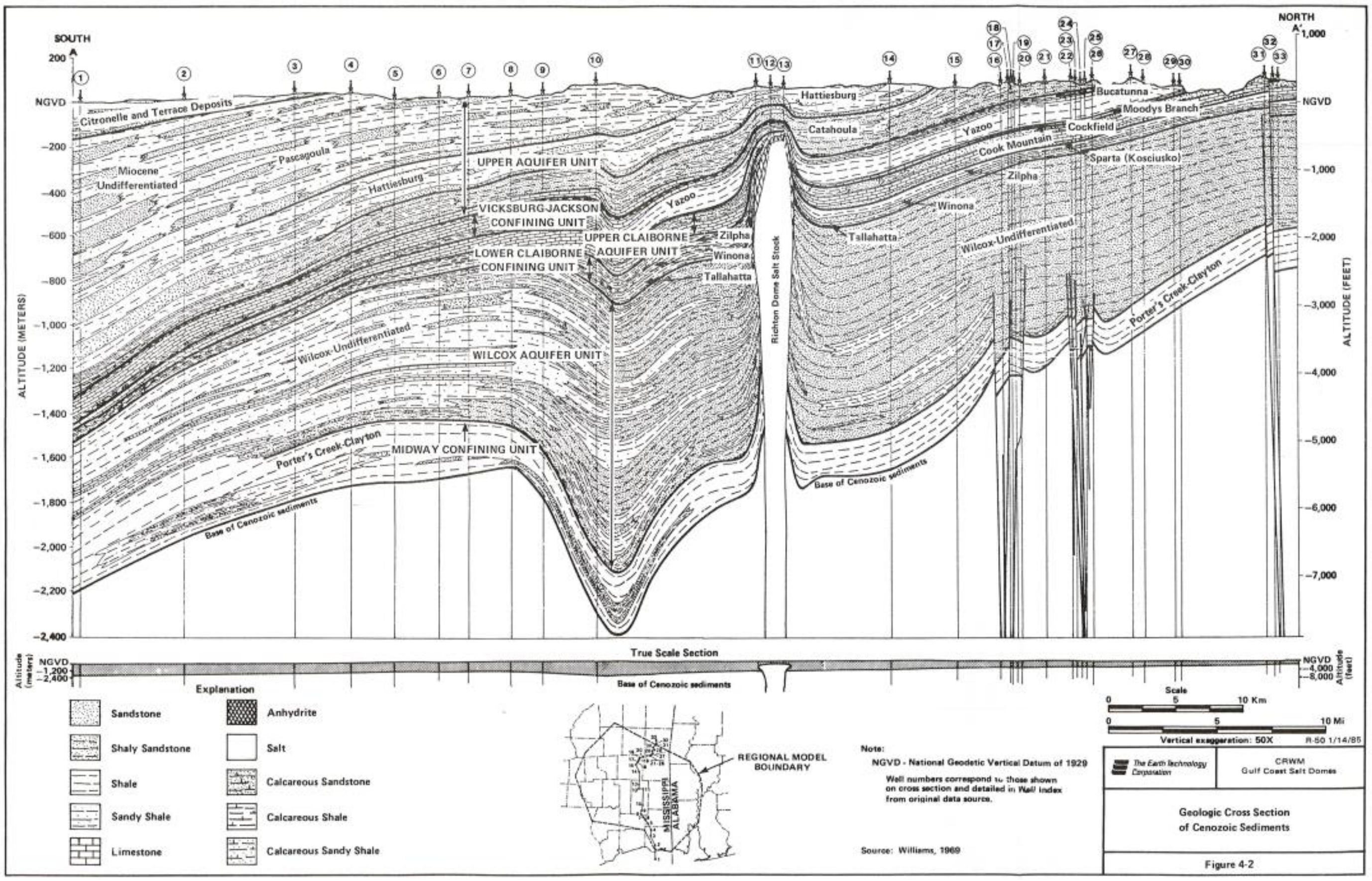


Figure 587. North-south structural cross section across Richton Salt Dome taken from Williams, 1969, showing bedrock lithologies and southerly dip. South of Richton Salt Dome is the Perry Basin, a salt withdrawal basin. Image 2438.

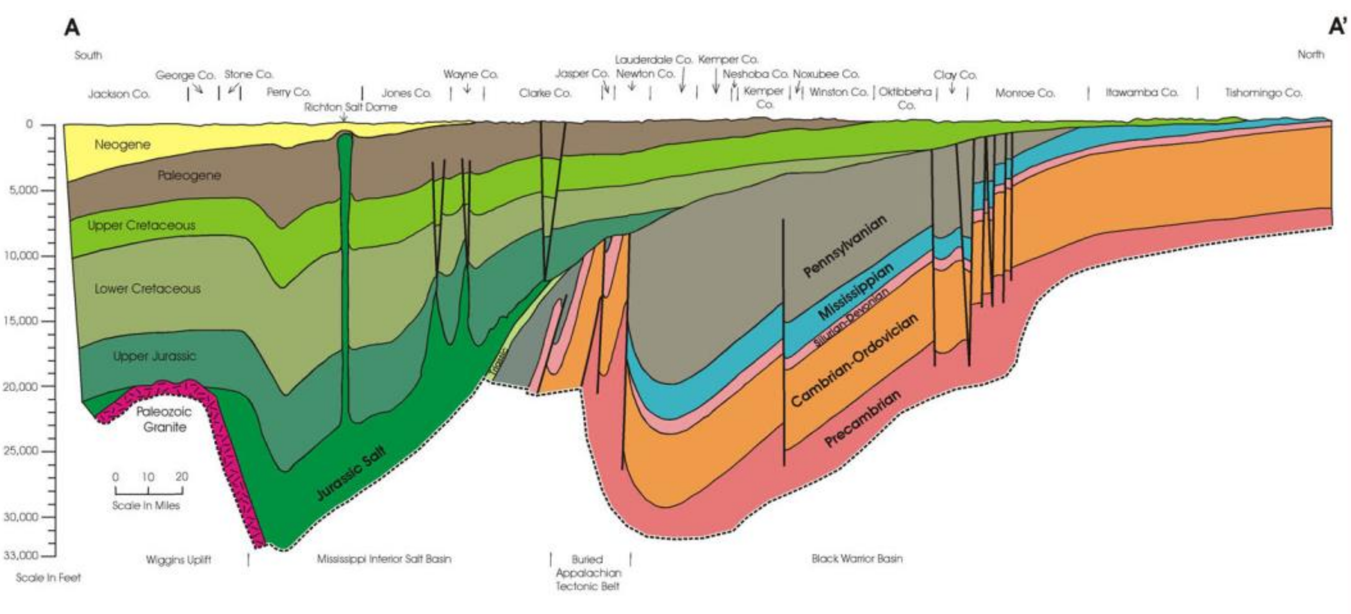


Figure 588. North-South structural cross section A-A' from the Mississippi-Tennessee State Line to Horn Island in the Gulf of Mexico from Dockery and Thompson, 2011, showing Richton Salt Dome.

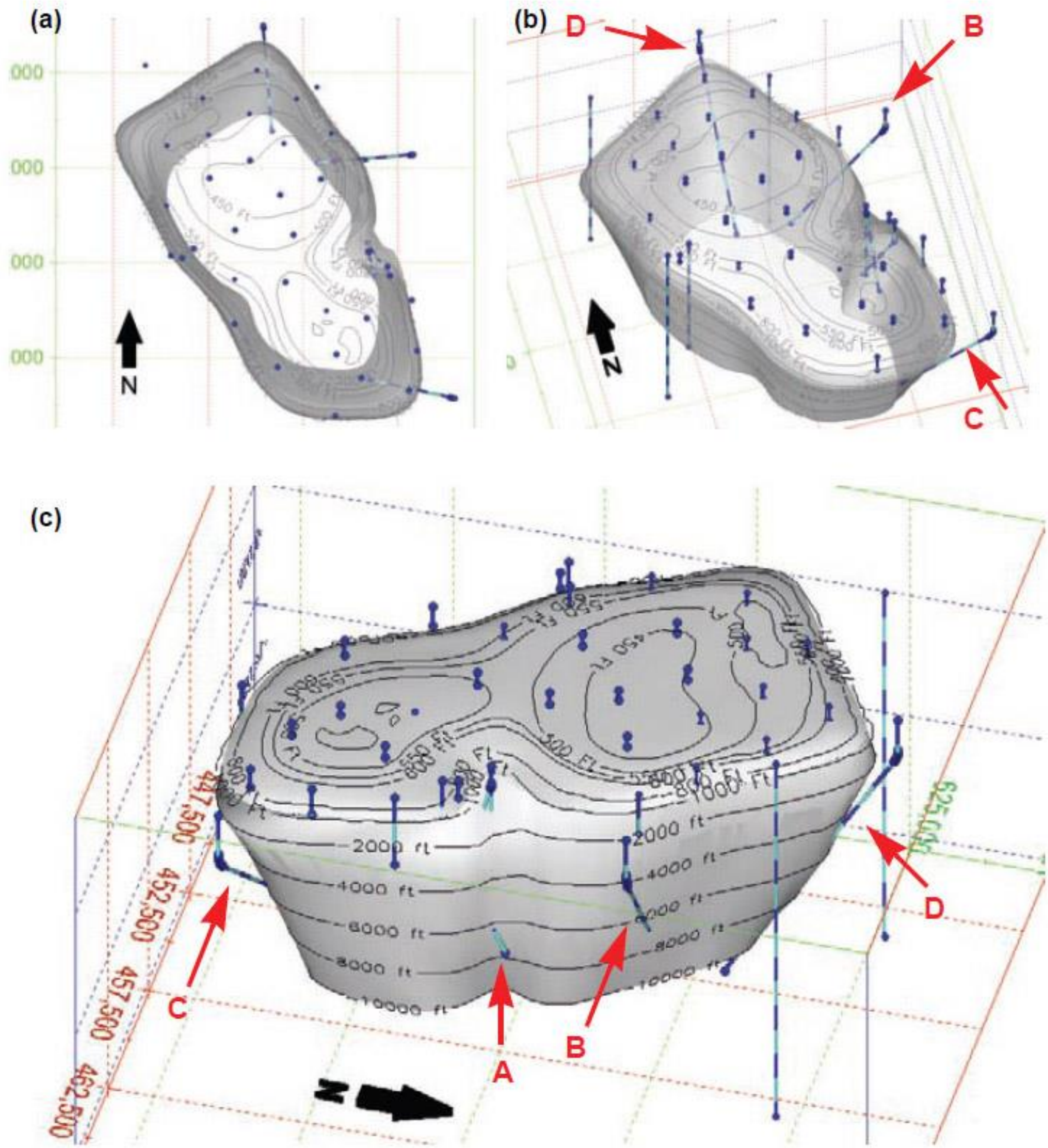


Figure 589. Three-dimensional visualizations showing relationships of deviated well paths to the modeled salt margin of the Richton salt stock (from Lord et al, 2007). Image 2437.

dry climate, remoteness, stable geology, deep water table, and closed water basin.

Evironmentalists and the state of Neveda opposed the Yucca Mountain site due to possible earthquake activity and seepage into groundwater that might connect to the Colorado River. Such concerns left Yucca Mountain in limbo during the Clinton Administration, even thought the Nuclear Waste Policy Act required the federal government to begin accepting nuclear waste from industry by 1998. On July 23, 2002, President Bush signed House Joint Resolution 87, allowing DOE to establish Yucca Mountain as the national repository. In June 2008, OCRWM applied for the Nuclear Regulatory Commission (NCR) license to open Yucca Mountain for business by 2017.

Figure 590. Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, is the only long-term geologic repository for nuclear waste in the United States (Wikipedia).

Figure 591. Location of U.S. defense waste generating and storage sites from which transuranic radioactive waste is sent to WIPP.

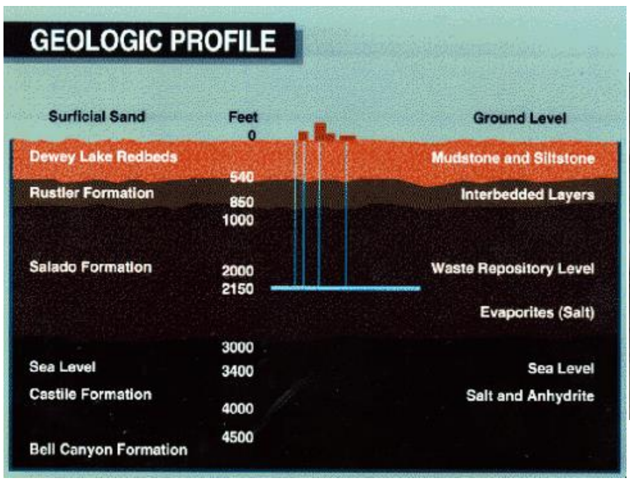


Figure 592. Geologic profile of WIPP at Carlsbad, New Mexico. Fresh-groundwater aquifers occur in the Rustler Formation above the repository.

Figure 593. WIPP's Room 7 in Panel 7, empty in October 2013, where airborne radiation was first detected underground on February 14, 2014. More tests confirmed the presence of radioisotopes of americium and plutonium in above-ground air filters.

In 2010, the Yucca Mountain project was defunded, bringing an official end to OCRWM the following year. President Obama's Blue Ribbon Commission released it's final report on January 26, 2012, which identified 72,000 tons of spent nuclear fuel stored at both operating and closed reactors in 35 states, awaiting a disposal solution. More than $15 billion was spent on the Yucca Mountain project.

In a May 21, 2014, press release, Mississippi Public Service Commissioner Brandon Presley celebrated the end of collection fees to support the nuclear waste storage site at Yucca Mountain, Nevada.. "The U.S. Court of Appeals for the D.C. Circuit issued its ruling in November 2013, ordering the DOE to cease collection of the fee until such time as either DOE resumes development of Yucca Mountain or until Congress modifies the statutory framework and provides for an alternative waste management plan. The DOE submitted a proposal to comply in January 2014, but continued to collect pending a request for review of the Court's decision. That request was denied in March.." Presley estimated that Mississippi ratepayers will pay $3.7 million less on their power bills.

Waste Isolation Pilot Plant (WIPP). Today the only long-term geologic repository for nuclear waste is the Waste Isolation Pilot Plant in Carlsbad, New Mexico (**Figure 590-593**). The plant is the world's third deep geological repository licensed to permanently dispose of transuranic radioactive waste produced at government research and nuclear weapons facilities (Figure 540) for 10,000 years. The repository is in 3,000-foot-thick bedded Permian salt (Salado and Castile formations) 2,150 feet below ground level and 1,000 feet above sea level and is located in the Delaware Basin in Eddy County, New Mexico (**Figure 591**).

Figure 594. Empty nuclear waste containers sit in front of the Waste Isolation Pilot Plant near Carlsbad, New Mexico, on March 6, 2014 (AP Photo).

The first nuclear waste arrived at WIPP on March 26, 1999, from Los Alamos National Laboratory. Some 9,207 shipments of 72,422 cubic meters of waste were received by the plant as of December 2010. The transuranic waste received consists of materials that have come in contact with radioactive substances such as plutonium and uranium and include gloves, tools, rags, and machinery used to produce nuclear fuel and weapons. Though much less potent than nuclear reactor byproducts, this waste will remain radioactive for 24,000 years.

WIPP experience its first radioactive leak on the evening of February 14, 2014. Trace amounts of airborne radioactive americium and plutonium particles were found above ground a half mile from the facility. On February 26, 2014, the Department of Energy announced that 13 of their workers tested positive for radiation exposure; all were above ground when contaminated. Inside the repository, high levels of alpha and beta radiation were detected by air monitors in Room 7 in Panel 1 (**Figure 592**). One explanation for the leak was the collapse of a salt roof, which crushed storage container, releasing radioactive particles.

A second radiation leak was detected by air-monitoring stations near the WIPP on March 11, 2014, about a month after the first leak. Engineers believed the contamination to have come from the previous deposits for the first leak, which adhered to the inner surface of the exhaust ductwork and said such low-level releases were anticipated. **Figure 594** shows empty nuclear waste containers at the Pilot Plant.

NATURAL GAS STORAGE AT EMINENCE SALT DOME

Bérest and Brouard (2002) reported on the safety of salt caverns used for underground storage and summed up the risks as much safer and environmentally friendly than above ground storage in steel and concrete tank farms. Eminence Salt Dome in Covington, Mississippi, was the first salt dome used for the construction (in 1970) of a solution-created salt cavern used for the storage of natural gas. The advantages of storing natural gas in salt include (from Duke Energy News Release, June 25, 2001):

1. It is as strong as concrete.
2. It is virtually impermeable to liquid and gaseous hydrocarbons.
3. It acts like plastic, allowing it to close and seal fractures that might occur.
4. It offers high natural gas deliverability in which gas can be withdrawn at a moment's notice or be filled equally fast.

The disadvantages for gas-filled salt caverns is that the gas pressure must be less than the formation pressure to avoid fracturing the cavern walls. In **figures 580-582**, the tall cylindrical cavern in Eminence Dome extends to a depth of 2,000 meters. This is the greatest depth for those solution caverns show in **Fig-**

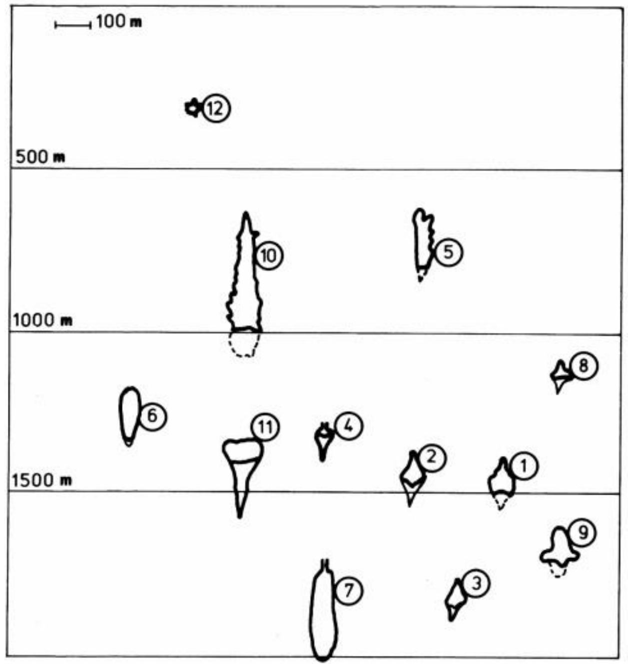


Figure 595. Solution-mined caverns: (1) Tersanne, France, (2) Etrez, France, (3) Atwick, England, (4) Kiel, Germany, (5) Huntorf, Germany, (6) Epe, Germany, (7), Eminence, USA, (8) Melville, Canada, (9) Regina, Canada, (10) Manosque, France, (11) Hauterives, France, and (12) Carresse, France (from Bérest and Brouard, 2002).

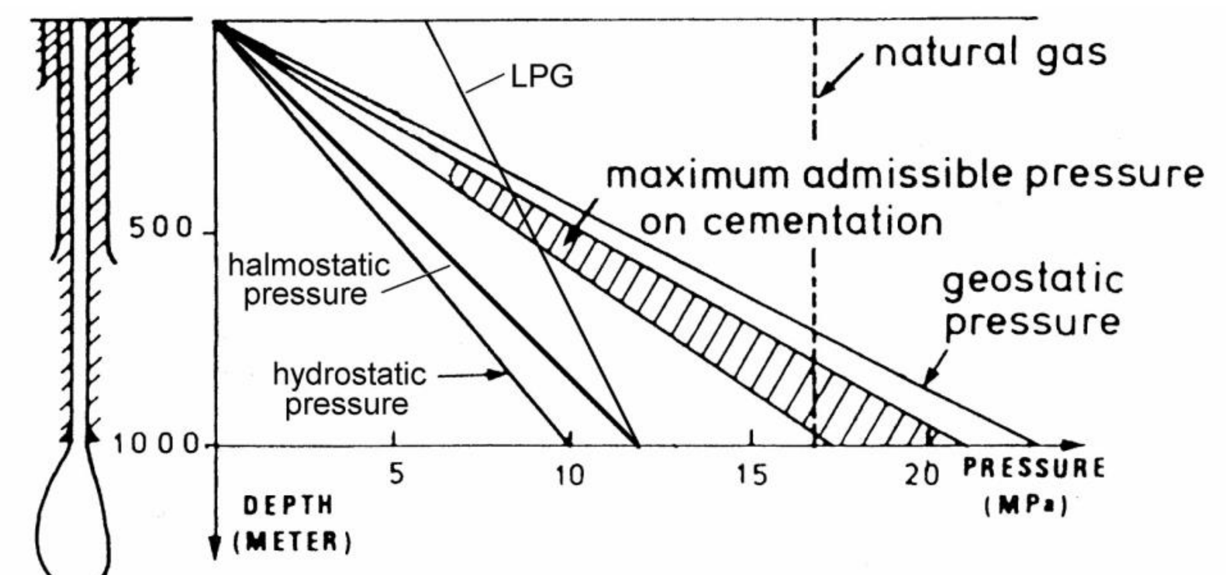


Figure 596. Pressure distributions for a cavern at 1000 meters. The geostatic pressure is the natural stress in a sedimentary formation with a density of 2,200 kilograms per cubic meter, which equals 22 megapascals (MPa) at a depth of 1000 meter (=3,191 psi). This pressure must never be exceeded by any stored fluid, and there must be a safety margin, or there is a risk of fracturing or a drastic permeability increase. Natural gas maintains the same pressure from the top to the bottom of the hole (from Bérest and Brouard, 2002).

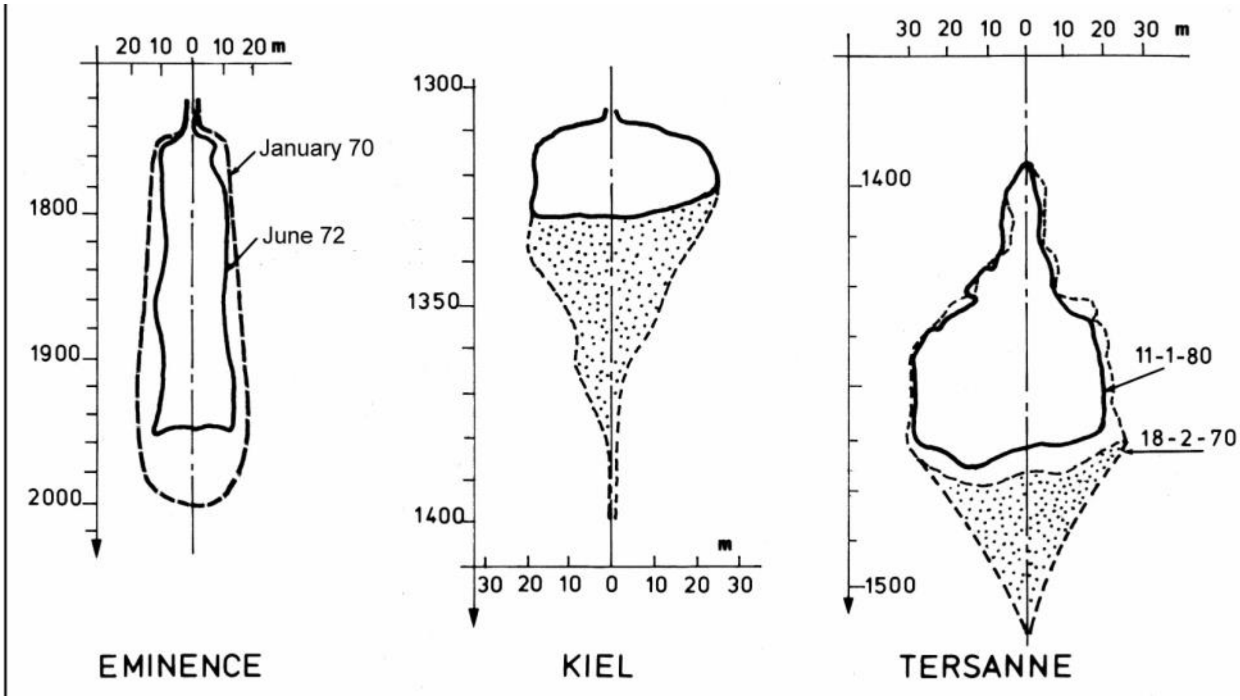


Figure 597. Creep effects in Eminence (Mississippi), Kiel (Germany), and Tersanne (France). Dotted surfaces represent insoluble sediments at the cavern bottom (Bérest and Brouard, 2002). The Kiel cavern shows no creep; the Tersanne cavern shows creep over ten years, and the Eminence cavern show creep over 2.5 years.

ure 595. At this depth, the geostatic pressure is around 44 megapascals, and, as shown in **Figure 596**, pressure created a salt creep that filled the bottom and compressed the flanks of the cavern over a 2.5-year period (**Figure 597**). A possible solution to minimize creep and to recover more of the stored gas is an isobaric gas cavern with constant pressure storage, using brine. Such caverns are used in Europe for LNG receiving terminals, where tankers need to unload the liquid natural gas within only a few hours (**Figure 598**). An obstacle to this design for salt-dome caverns is that they are ten times larger than the bedded-salt caverns in Europe and would require ten times more brine and brine storage.

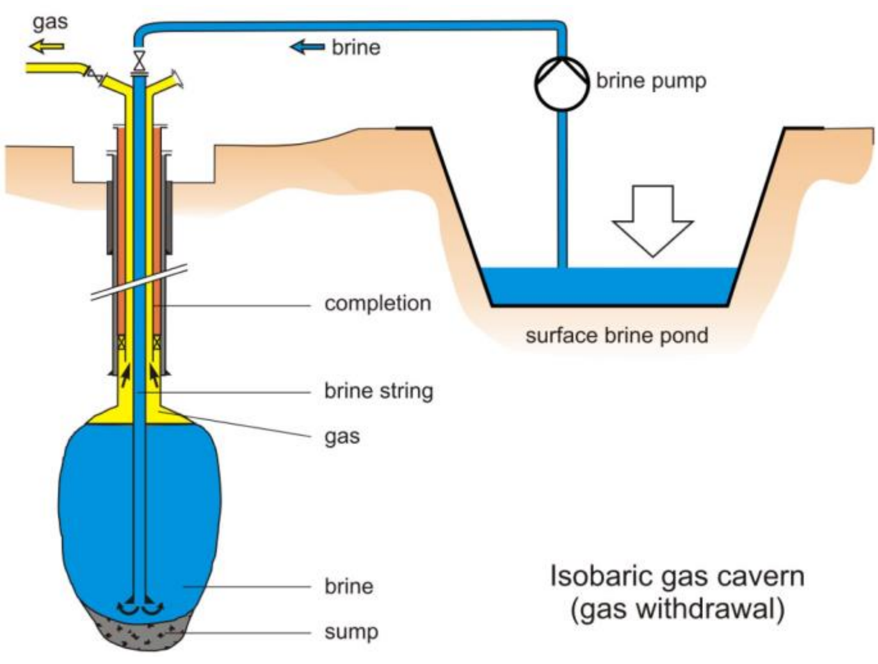


Figure 598. Isobaric gas cavern with constant pressure maintained by brine withdrawal or brine pumping (from Gillhaus, 2007).

Transco Gas Pipe Line Company, LLC, one of several pipelines owned by The Williams Companies, Inc., operates the seven salt caverns in Eminence Salt Dome. According to its website, Transco has: (1) a peak design capacity of 9.8 billion cubic feet per day, (2) a seasonal storage of 200 billion cubic feet, (3) supply areas in the Gulf Coast, Appalachia, and imported liquid natural gas (LNG), (4) market areas in the Southeast, Mid-Atlantic, and Northeastern states, (5) 10,200 miles of transmission pipeline, and (6) 52 compressor stations. Salt caverns 1-4 were certificated in the early 1970s. Caverns 5-7 were certificated in 1991.

The following account of event is taken from a U.S. Federal Energy Regulatory Order (Docket Nos. CP11-551-000 and RP12-993-001) issued on February 7, 2013. On December 26, 2010, Transco detected a large, unexpected pressure drop in Cavern 3 (a drop of 357 pounds per square inch in one minute) and determined that gas was leaking from the cavern. The company's initial response to this leak by flowing 306 MMcf of gas into its pipeline system.. Another leak from the well head of Cavern 3 sent water shooting from water wells on site. In response to the well-head leak, Transco vented a least 1 Bcf of gas from Cavern 3 from December 28, 2010, to January 3, 2011. On January 4, 2011, Transco began flaring some 9.8 MMcf of gas from Cavern 3, which ceased when its production tubing became clogged with debris.

On December 31, 2010, Transco discovered gas escaping externally from the ground around the wellhead of Cavern 1. This gas continued to escape until March 10, 2011, when a large cave-in sealed off the flow. On January 4, 2011, due to the gas escape at the surface of Cavern 1 and the determination that the reduced pressure in Cavern 3 posed a risk to the salt pillars separating caverns 1 and 2, Transco began the reduction of pressures of caverns 1 and 2 by flowing gas into its pipeline.

Transco estimated that the total storage at Eminence Salt Dome on December 26, 2010, prior to the gas leaks, was 21.282 Bcf of gas stored in six of its seven caverns, in the following amounts.

Cavern 1	1.793 Bcf
Cavern 2	1.126 Bcf
Cavern 3	2.719 Bcf
Cavern 4	0 Bcf
Cavern 5	5.771 Bcf
Cavern 6	4.128 Bcf
Cavern 7	5.745 Bcf

Total Capacity	20.5 Bcf
Working Gas Capacity	15.0 Bcf
Cushion Gas Capacity	5.5 Bcf
Maximum Pressure	3,800 pounds per square inch absolute
Minimum Pressure	1,115 psia
Acreage	450 acres
I/W Wells (caverns)	7
Obs. Wells	2
Storage formation	Louann Salt
Caprock	Not identified
Peak Deliverability	1,500 MMcf
Max Injection	144.6 MMcf
Horsepower	15,635 hp

A Summary of Eminence Storage Field's current certificated operation parameters, including caverns 1-4 (Federal Energy Regulatory Commission,. Order Approving Abandonment, Amending Certificate Authority, and Granting Clarification, Issued February 7, 2013) is given above.

On January 4, 2011, Transco began drilling monitoring wells in the surrounding freshwater zones to mitigate the threat to the storage facilities, to determine the footprint of the escaped gas, and to confirm the gas not migrated beyond the field's boundaries into residential water wells. Transco decided on January 24, 2011, to take caverns 1 and 3 out of service and began filling Cavern 1 with water. Cavern 2 was filled with water after a shut -in pressure test indicated a slow leak. An overall evaluation of caverns 1-4 by a consulting firm (Subsurface Technology, Inc.) concluded that none of the four caverns should continued to be used for long-term gas storage services due to their documented history, condition, and damage caused by salt creep. Transco thus decided to abandon and remove the caverns from service. Originally, Transco had planned to further investigate Cavern 4 to determine if the cavern could be salvaged by side-tracking the collapsed casing, but, because of the failure of Cavern 3 and consultant recommendation, the company decided to abandon the cavern. To accomplish the abandonment of the four original caverns, all will be filled with water with 210-barrel tanks above ground to collect water that flows back due to salt creep. The estimated cost of abandonment activities was $76 million.

Cavern 1-4 were constructed in a square formation with a distance of 700 to 990 feet between wells and were place into service, respectively, in 1970, 1971, 1973, and 1973. The salt pillar distance between any two caverns was at least 580 feet, a distance greater than the 300 feet required by the Mississippi State Oil and Gas Board.

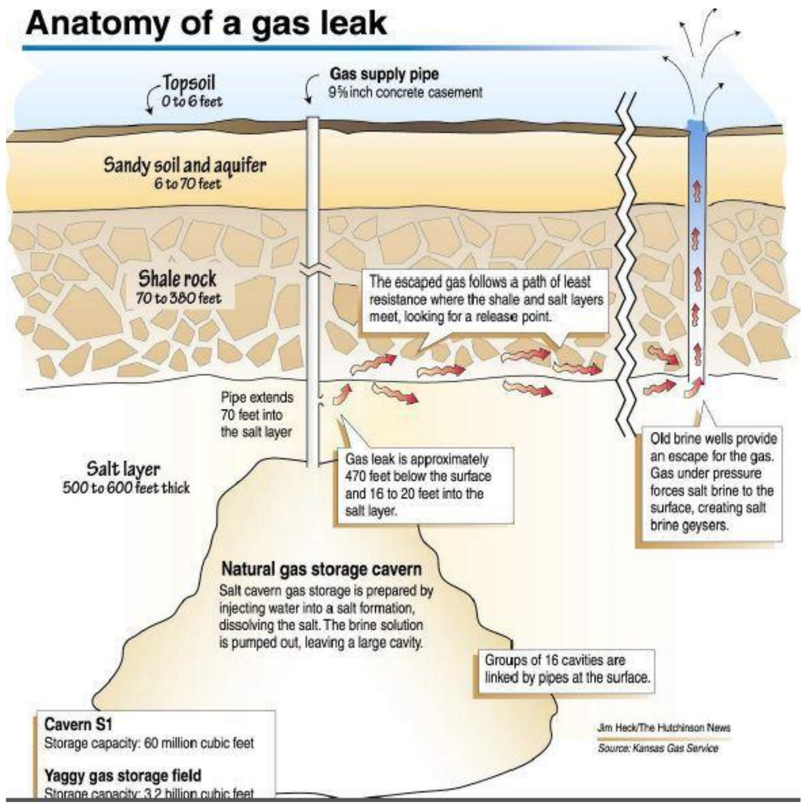


Figure 599. Anatomy of a bedded salt gas storage cavern methane release in Hutchinson, Kansas, on January 17, 2001 (hutchnews.com).

The geostatic pressure for Cavern #1, at a depth of 1725 to 2000 meters, was around 40 MPa (5600 psi). The first gas injection into the cavern was completed by mid-1970. In October 1970, the gas pressure was lowered to 6 MPa (840 psi), maintained at that pressure for two months, and then increased to 28 MPa. A large volume loss was suspected after a similar pressure cycle was preformed in 1971. By April 1972, bottom heave raised the cavern floor by 36 meters with a total volume loss of 40% as determined by a sonar survey made in June 1972 (**Figure 597**) (Berest and Djizanne, 2012). Caverns 1 and 3 were re-leached to double their sized in 2003 and 2001, respectively, to counter cavern shrinkage due to salt creep. Cavern 4 was taken out of service and shut in 2004. The lost capacity of Cavern 4 was replaced by permanently enlarging the other caverns.

Salt creep is a geological process where salt flow fills a void over time. All salt caverns require periodic re-leaching to return the caverns to their designed or authorized size. Cavern shrinkage due to salt creep induces stress on the casing strings, which can result in damage to the casing string and/or cement bond between the salt formation and the casing (**Figure 599**). Repeated stressing, if severe, can cause cavern failure. The four abandoned caverns in Eminence Storage Field have multiple casing part separations and repairs, but the actual cause of the December 2010 incident has not been determined, so damage to the casing string as a factor cannot be declared.

Transco continues to operate caverns 5-7, which have a combined storage capacity of 15.025 Bcf (10.05 Bcf of working gas capacity and 4.975 Bcf of base gas capacity) and a certified deliverability of 1,500 MMcf per day to 1,200 MMcf per day. Cavern 7 has one casing part at 4,287 feet. While Eminence Storage Field is certificated for a maximum operating pressure 3,800 pounds per square inch absolute (psia—pressure relative to a vacuum and not atmospheric pressure), Transco's testing shows that gas leaks into the caprock if Cavern 7 is operated at 3,600 psia. Transco proposed a maximum pressure of 2,775 psia at the casing shoe for Cavern 7, at which the cavern would maintain integrity and not leak. At this pressure the cavern would certificate at 5.172 Bcf of gas.

Figure 600. A 300-foot-high water geyser vents from a water well at the Eminence Gas Storage facility in Covington County near the Jones County line. An underground storage cavern was discovered to be leaking around 8 p.m. on Monday, December 31, 2010 (Matt Bush/Hattiesburg American). Image 2527.

Figure 601. "Mud volcano" vented from an old seismic test hole in Covington County near the Eminence Gas Storage facility. The crumpled plastic milk jug is believed to be the object used to plug the hole. Picture was taken by James Starnes on January 5, 2011. Image 2528.

Figure 602. Blue-gray silty mud sprayed on tree tops from a geyser and mud flow that filled a cow pond downhill and overflowed the pond to enter a nearby creek. Picture was taken by James Starnes on January 5, 2011. Image 2529.

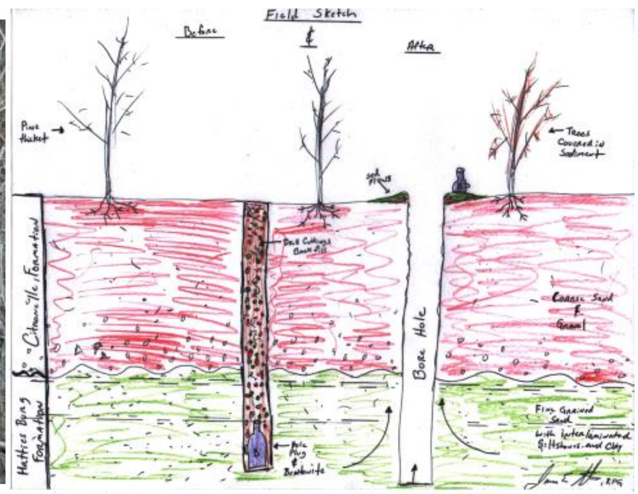


Figure 603. Rough field sketch by James Starnes showing the plugged test hole before (left) and after (right) the gas blowout. The mud is from the fine-grained sediments of the Hattiesburg Formation. Image 2530.

Transco prepared groundwater flow contour maps that showed groundwater to flow in a southeast direction over the Eminence Storage Field. Water samples taken of public supply wells and 23 private water well found only two wells to have detectable levels of methane in the headspace analysis and one with concentrations above the laboratory detection limit (1 milligram per liter) in the dissolved-phase (dissolved in water). The dissolved-phase elevated methane levels were significantly below U.S. Department of Interior, Office of Surface Mining's "Recommended Action Levels."

The initial December 26, 2010, gas leak from Cavern 3 sent water shooting into the air from on-site water wells. In one well, the pump blew out of the ground, and water shot 300 feet into the air (**Figure 600**). Another interesting phenomena on adjacent property was the flowage of a "mud volcano" from what appeared to be an old seismic test hole plugged with a wadded up milk cartoon (**figures 601-603**). The mud flow was investigated after the fact by James Starnes and John Marble of MDEQ's Office of Geology on January 5, 2011.

HUTCHINSON, KANSAS, GAS STORAGE LEAK

On Wednesday morning, January 17, 2001, technicians at the Yaggy Underground Natural Gas Storage Field, a field which consisted of salt caverns (called jugs) in bedded salt of the Hutchinson Salt Member of the Permian Wellington Formation, saw a dramatic drop in pressure in the S-1 jug (Allison, 2001). Later that morning, a natural gas explosion rocked the downtown area of Hutchinson, Kansas, some 8 miles to the southeast (**figures 604-605**), blowing out the windows of Woody's Appliance Store and the adjacent Décore Shop. Customers and workers from both stores staggered into the streets, dazed and shaken. Soon the two businesses were in flames (**Figure 606**). That evening, geysers of brine and natural gas, some reaching 30 feet in height (**figures 607-608**), blew from abandoned brine wells located 2 to 3 miles northeast of town from holes drilled for salt production in the 1880s. The next day, natural gas coming from a forgotten brine well under a mobile home exploded, killing two people.

Hucthinson officials ordered the evacuation of residences and businesses, some of which were not deemed safe until the end of March. Suspicion as to the source of the leaking gas quickly focused on Yaggy Natural Gas Storage Facility west of town. The problem was: How could leaking natural gas move 8 mile underground in a few hours to explored in downtown Hutchinson?

Yaggy Field had 62 active gas storage jugs that could supply 150 million cubic feet (MMcf) of gas per day and could hold 3.5 billion cubic feet of gas at pressures of about 600

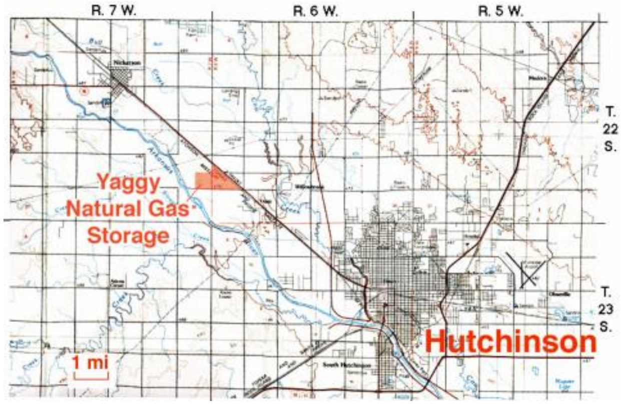


Figure 604. Location map of the Yaggy Natural Gas Storage Facility and Hutchinson, Kansas (from the Kansas Geological Survey). Image 2501.

Figure 605. Location map of the downtown explosion, geysers, and trailer park explosion in Hutchinson, Kansas (from the Kansas Geological Survey). Image 2502.

Figure 606. The Décore Shop immediately after the natural gas explosion on Wednesday morning, January 17, 2001 (left), and minutes later on fire (right) in downtown Hutchinson, Kansas (from the Kansas Geological Survey). Image 2503.

Figure 607. Thirty-foot geyser of natural gas, dirt, and brine from an abandoned brine well northwest of the Big Chief Mobile Home Park in Hutchinson, Kansas, where a mobile home exploded on January 18, 2001, killing two people (from the Kansas Geological Survey). Image 2504.

Figure 608. Small geyser of gas and brine near a railroad track in eastern Hutchinson, Kansas (from the Kansas Geological Survey). Image 2505

pound per square inch.. The S-1 jug, with a leaking pipe, could hold 60 million cubic feet of gas. Kansas Gas Service realized that the S-1 jug had been leaking at a low level since it was filled three days earlier. A down-hole-camera probe of the jug's production pipe revealed a large curved slice in the casing at about 600 feet as the source of the gas leak.

Gas from the leaking casing moved up hole until it reached an impenetrable gypsiferous zone at the base of the overlying Ninnescah Shale (**Figure 609**). It then moved updip along the Upper Wellington Shale-Ninnescah Shale boundary until it encountered the bore holes of abandoned bine wells, though which the gas vented to the surface with explosive results (**Figure 610**). One such well was discovered in the basement of one of the stores destroyed in downtown Hutchinson. It had been drilled to provided brine waters for a hotel spa. Geologists with the Kansas Geological Survey mapped the top of the Wellington Formation and found an anticlinal structure beneath the city into which the gas had accumulated (**Figure 611**).

Figure 609. Core of the lower Ninnescah Shale with gypsum-filled fractures that served as a seal for rising natural gas from the leaking pipe in the S-1 jug. Core is from a well drilled close to the many geysers on the east side of Hutchinson, Kansas (from the Kansas Geological Survey). Image 2506.

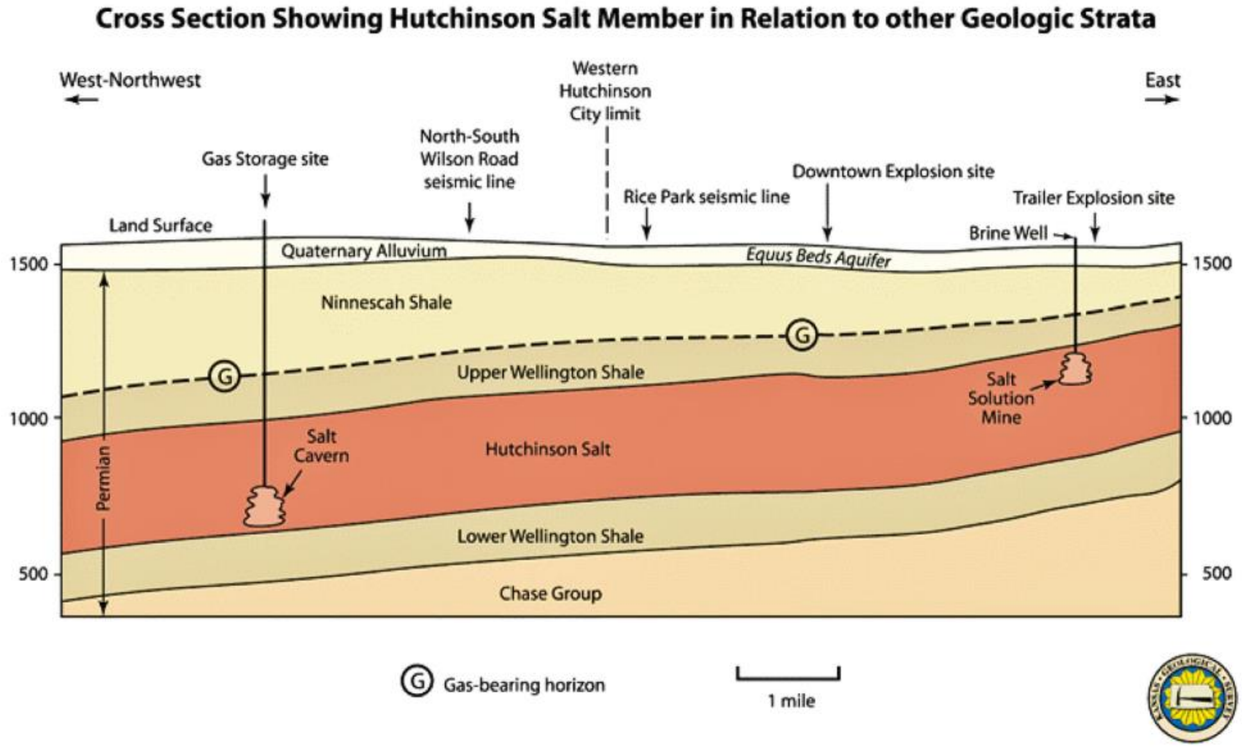


Figure 610. Northwest-southeast cross section through the Yaggy Underground Natural Gas Storage Field (at left) and the brine well at the Big Chief Mobile Home Park (at right) in eastern Hutchinson, Kansas, which exploded and killed two people on January 18, 2001. Leaking gas from the storage field followed a geologic boundary at the contact of the Wellington and Ninnescah formations (labeled G) (from the Kansas Geological Survey). Image 2507.

The Kansas Geological Survey ran a four-mile-long seismic reflection survey between the Yaggy Field and the City of Hutchinson, which showed gas pockets as bright spots along two anomalous zones. Kansas Gas Service drilled both seismic anomalies and found gas at the predicted locations and depths. Cores of the anomalous zones found the producing zone to consist of thin, tight dolomite layers below the contact of the Wellington and overlying Ninnescah Shale and about 200 feet above the Hutchinson Salt bed. By mid-March, Kansas Gas had drilled every potential target and gas flow rates and pressures in the vent wells were on a continuous decline. At a town hall meeting on March 29, 2001, the Kansas Geological Survey declared the city safe. The next day city officials allowed the last of the evacuees to return home. The crisis was over.

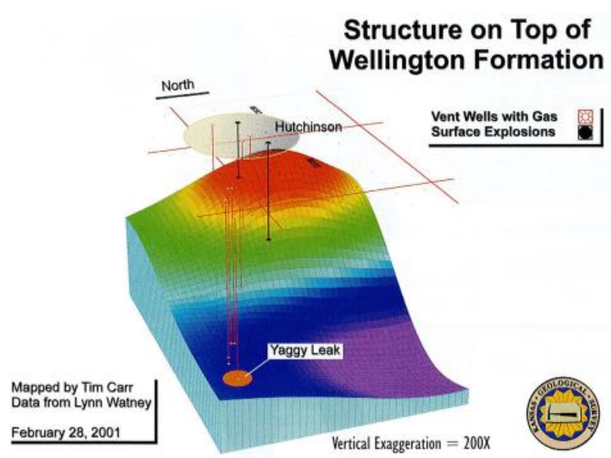


Figure 611. The Vaggy Storage Field gas leak followed geologic structure and migrated to the top of an anticline under Hutchinson, Kansas (Allison, 2001, p. 18). Image 2508.

CHAPTER 14. COASTAL GEOLOGY

The coastline of Mississippi's Gulf Coast is where the energy of a broad expanse of ocean in the Gulf of Mexico meets a seeming unmovable object, the North American Continent. However, ocean waves, long shore currents, tides, storm surges, and changing sea levels are constantly reshaping the coastline and the coastal area. The following are three articles from *Environmental News*. The first article gives a snapshot of the environmental geology of Jackson County as mapped in 1974; the second shows the effects of an ancient sea level rise, and the third shows how the Holocene geology of New Orleans contributed to the flooding of the city during Hurricane Katrina.

The following is, in part, from the December 2011 issue of *Environmental News*, v. 8, no. 2, February 2011, p. 6-9 (Dockery 2011) *Environmental Geologic Map, Jackson County, Mississippi.*

The title, *Environmental Geologic Map, Jackson County, Mississippi*, is not about a new map publication. In fact, this map was published by the Geology Department of the University of Mississippi in 1974—but, sometimes it's an old map that's needed. With the recent Gulf oil spill and such disasters as Hurricane Katrina, the *Environmental Geologic Map, Jackson County, Mississippi*, provides a valuable baseline to compare the coastal environments of 1974 with those of today (after such disasters). It also provides a baseline to measure the possible effect of rising sea level associated with global warming. The map contains 41 environmental geologic mapping units.

The Environmental Geologic Map of Jackson County was drawn using remote sensing to determine the extent of coastal and highland geologic environments in the county. The low marshes of Jackson County and the rest of the Mississippi coastline, which are regularly flooded by tides, are dominated by the salt-water smooth cord grass *Spartina alterniflora*. The color signature of this grass is easily distinguished and mapped by remote sensing. Thus marsh damage and deterioration due to hurricanes or oil spills can be detected in new imaging and compared with the 1974 *Environmental Geologic Map*. If the salt-water marsh expands upstream on the Pascagoula River estuary due to sea-level rise or local subsidence, that can also be detected.

Jackson County's Pascagoula River and estuary were touted in the Mississippi Public Broadcasting (MPB) film *The Singing River, Rhythms of Nature*, which premiered on MPB on November 13, 2003, as the last unimpeded major river system in the lower 48 states (i.e. not confined by dams or levees). The Pascagoula River system has the second largest basin in Mississippi, comprising most of southeastern Mississippi, and covering some 22 counties. It is 164 miles long and 84 miles wide and drains an area of about 9,000 square miles.

The Singing River featured the Pascagoula River system from its headwaters in the bedrock of the Tallahatta Formation along the Chunky River in Lauderdale County to Pascagoula Bay and the adjacent coastal environments. While the writer (Dockery) was a graduate student at the University of Mississippi in 1973, the Department Head, Dr. Min-

Figure 612. At left, "dedicated" Ole Miss graduate students David Dockery (in front) and MerleDuplantis (in back). At right, Merle Duplantis and others in route to the Jackson County flyover. Pictures taken in November of 1973. Image 1840.

Figure 613. At left, the meander belt of the Pascagoula River in northern Jackson County, Mississippi. At right, Mississippi coastal marshes along the Pascagoula River in Jackson County. Pictures taken in November of 1973. Image 1841.

Figure 614. At left, tidally-influenced saltwater marshes of the Pascagoula River estuary in Jackson County, Mississippi. At right, tidal marshes on the lower Pascagoula River with Marsh Lake at upper right and the coastline beyond. Pictures taken in November of 1973. Image 1842.

Figure 615. At left, tidal marsh on Belle Fontaine Point in Jackson County, Mississippi. At right, retreating shoreline and black beach where erosion has exposed marsh sediments underlying the beach sand at an unknown location in Jackson County. Pictures taken in November of 1973. Image 1843.

shew, took the students of his fall semester Advanced Stratigraphy Class on the Ole Miss airplane for a flyover of the river, estuary, and adjacent coastline as a "field check" of the *Environmental Geologic Map* before its publication. **Figure 612** shows "dedicated" Ole Miss

Figure 616. At left, tidal marsh on Belle Fontaine Point in Jackson County, Mississippi. At right, retreating shoreline and black beach where erosion has exposed marsh sediments underlying the beach sand at an unknown location in Jackson County. Pictures (slides 8-18 and 7-19) taken in November of 1973.

graduate students and the Ole Miss airplane before the flyover. **Figure 613** shows the meander belt of the Pascagoula River and the river's upper estuary. **Figure 614** shows the lower estuary of the Pascagoula within view of the coastline. **Figure 615** shows the mouth of the Pascagoula River and the beach and sand shoals at Belle Fontaine Point. **Figure 616** shows the salt-water marsh behind the beach at Belle Fontaine Point and an eroded beach nearby. **Figure 617** is the *Environmental Geologic Map, Jackson County, Mississippi*. A digital copy of this map was made available to us by Charles Swann of the Mississippi Mineral Resources Institute at the University of Mississippi.

Geologic Map of Jackson County by Starnes and Stewart, 2017 (**Figure 618**), shows the effect of ancient sea level changes on the geology of Mississippi's Gulf Coast. Coastal terraces, those terraces running parallel to the coast, include the Pamlico Terrace at 0 to 30 feet above mean sea level (msl) (**Figure 619**), Big Ridge Terrace at 30 to 50 feet msl (**Figure 620**), and Good Hope Terrace at 50 to 110 feet msl (**Figure 621**). River terraces, those terraces running parallel to river courses, include the Wade Terrace at 30 to 50 feet msl (**Figure 622**), Big Point Terrace at 50-80 feet msl (**Figure 623**), Hurley Terrace at 80 to110 feet msl, Harleston Terrace at 110 to 130 feet msl, and Movella Terrace at 130 to 150 feet msl. Bedrock formations exposed at the surface in the county include the Pliocene Graham Ferry Formation and the Late Miocene Pascagoula Formation.

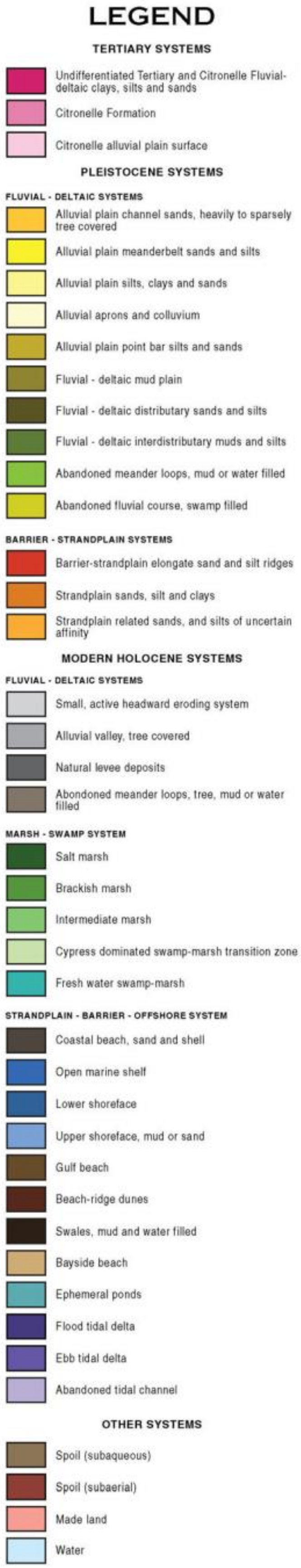
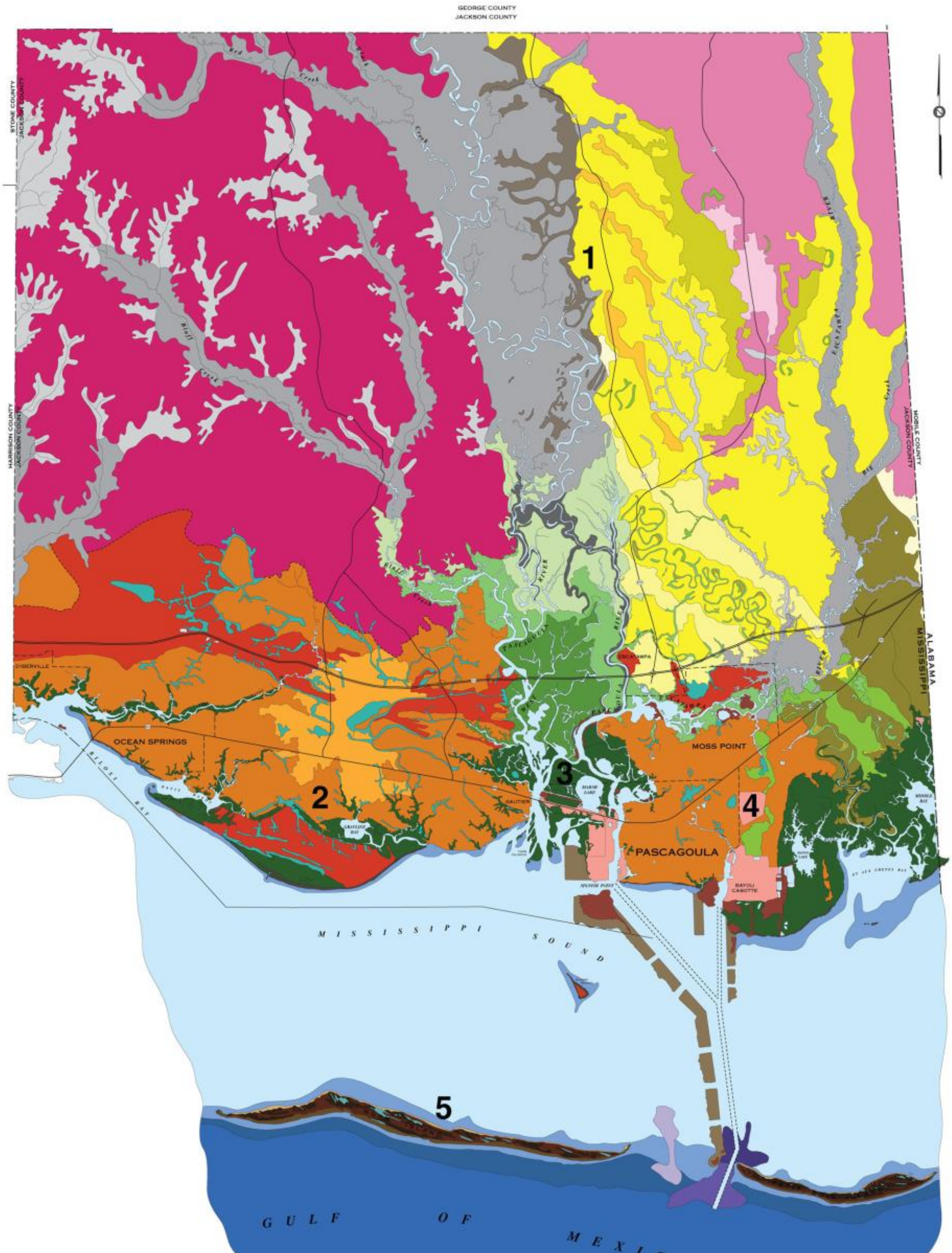


Figure 617. Legend (at left) and Enviromental Geologic Map (facing page) of Jackson County, Mississippi., by V. H. Minshew, C. A. Gaszzier, L. P. Malbrough, and T. H. Waller, 1974, Envrionmental Geological Analysis: Jackson County, Mississippi, Mississippi Mineral Resources Institute, The University of Mississippi. Image 1845.



ENVIRONMENTAL GEOLOGIC MAP
JACKSON COUNTY, MISSISSIPPI

GEOLOGY BY
THE UNIVERSITY OF MISSISSIPPI

Figure 619. Pamlico Terrace scarp at Davis Point southeast of Ocean Springs. The grassy plain in front of the scarp is post-Katrina fill. Photograph by James Starnes, May 10, 2017.

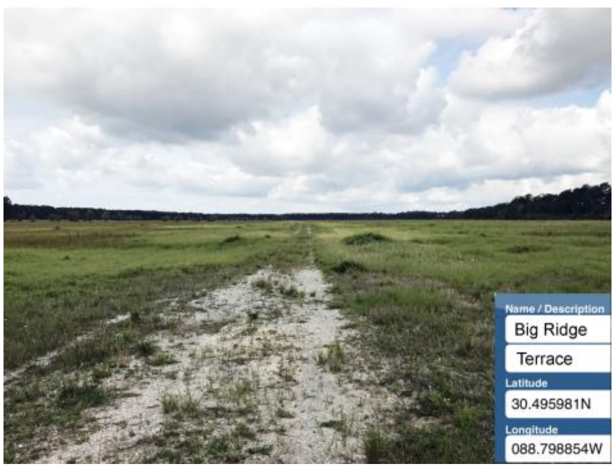


Figure 620. Big Ridge Terrace at 50 feet above mean sea level and south of Frank Snell Road and west of Redoak Swamp, Jackson County. Photograph by James Starnes, May 11, 2017.

Figure 621. Good Hope Terrace at Good Hope Church with flat areas at 100 feet and 90-100 feet above mean sea level, Jackson County. Photograph by James Starnes, May 10, 2017.

MAPPING UNITS

Figure 618A

ALLUVIAL FAN

Qaf — Holocene Alluvial Fans- Alternating silts, sands. Coarsest at the apex of the fan, fining laterally (radially) from the apex of the fan. May interfinger with Pascagoual River alluvium.

ALLUVIUM

Qal — Flood plain sands, silts, gravels, and clays. Lower-most reaches of stream alluvium may grade into tidally-influenced, brackish water marshes and muddy coastal deposits, (not mapped).

COASTAL TERRACES

Qtpc — PAMLICO COASTAL TERRACE
Interval: 0 to 30 feet; Terrace: 25 feet

Qtbrc — BIG RIDGE
Interval: 30 to 50 feet; Terrace: 50 feet

Qtghc — GOOD HOPE
Interval: 50 to 110 feet; Terrace: 100 feet

RIVER TERRACES

Qtwr — WADE TERRACE
Interval: 30 to 50 feet; Terrace: 50 feet

Qtbpr — BIG POINT TERRACE
Interval: 50 to 80 feet; Terrace: 70 feet

Qthur — HURLEY TERRACE
Interval: 80 to 110 feet; Terrace: 100 feet

Qthr — HARLESTON TERRACE
Interval: 110 to 130 feet; Terrace: 130 feet

Qtmr — MOVELLA TERRACE
Interval: 130 to 180 feet; Terrace: 150 feet

GRAHAM FERRY FORMATION

Tgf — Sand, dark greensih-gray, yellow to tan, micaceous and glauconitic (exclusively in the fine-grained sands), fine- to coarse-grained, predominantly quartzose, cross-bedded to massive; Laminar to thinly bedded quartz pea gravels in coarser fraction. Weathers to orange, purple, red, pink with reddish-brown colored pebbly ironstone residuum, Clay, green, gray, brown, weathers mottled purple to pink and white to reddish-brown, silty to sandy, locally lignitic.

PASCAGOULA FORMATION

Tp — Shallow marine to intertidal deposits, contains the marker fossil, Rangia johnsoni. Clay, green, gray, brown, and white; locally lignitic, locally calcareous and fossiliferous. Weathers mottled purple to pink and white to reddish-brown, silty to fine-sandy. Sand, dark greenish-gray and glauconitic, micaceous, locally lignitic, fine- to coarse-grained, predominantly quartzose, silicified wood common.

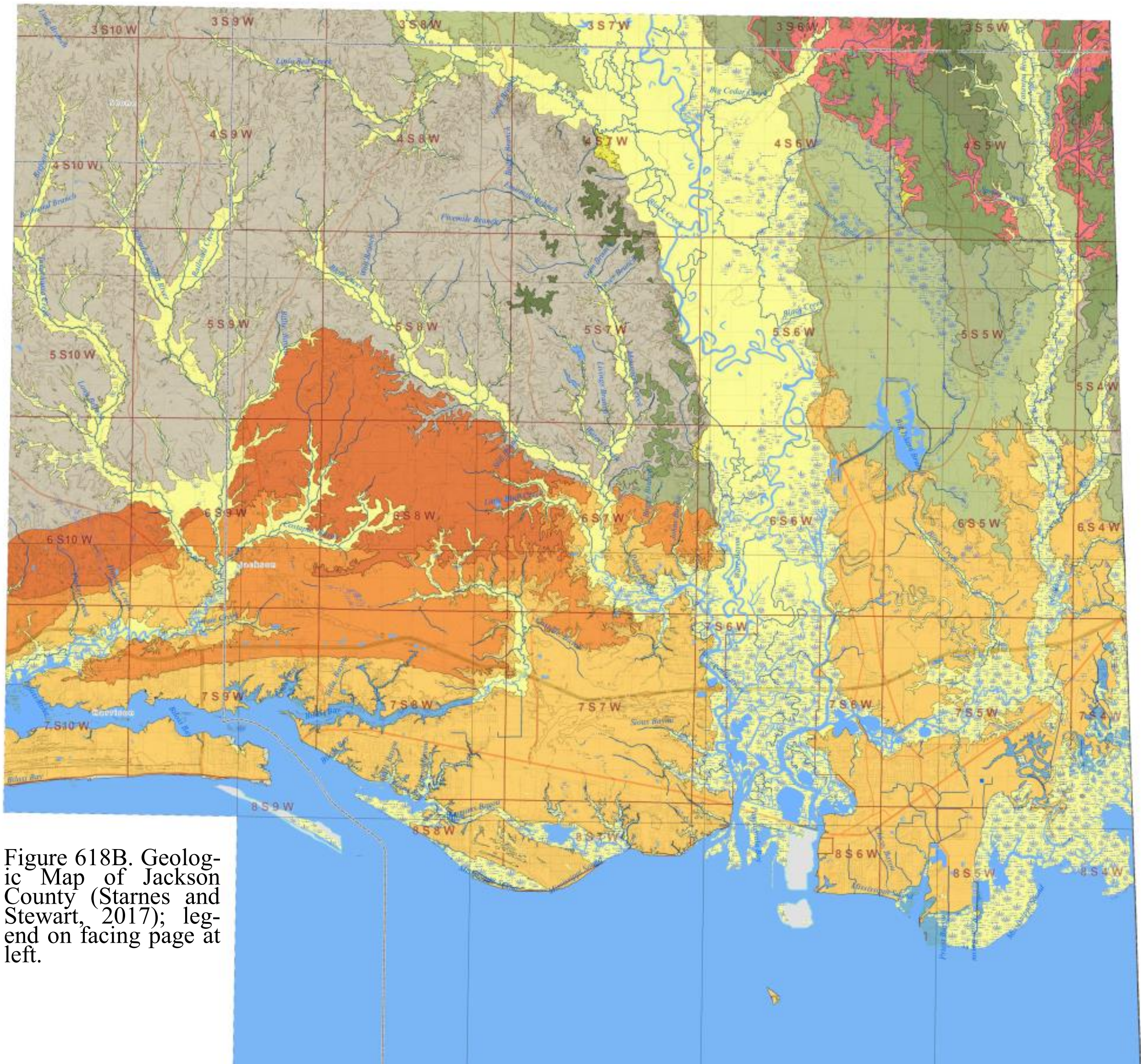


Figure 618B. Geologic Map of Jackson County (Starnes and Stewart, 2017); legend on facing page at left.

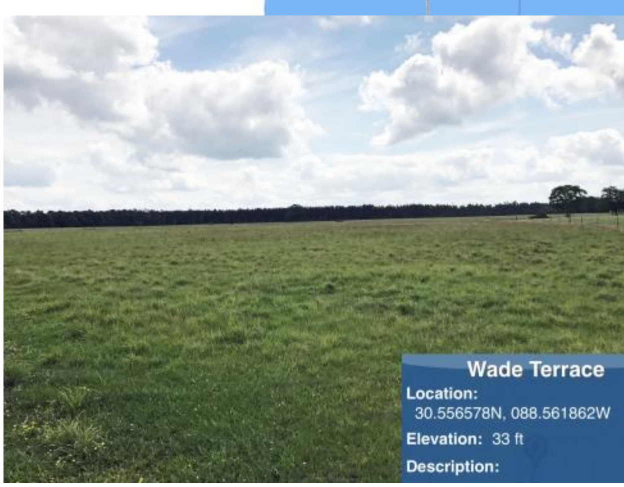


Figure 622. Wade River Terrace at 30 to 50 feet above mean sea level. Photograph by James Starnes, May 11, 2017.

Figure 623. Big Point Terrace at 50 to 80 feet above mean sea level. Photograph by James Starnes, May 11, 2017.

GLOBAL WARMING AND HIGH SEA LEVEL 125,000 YEARS AGO (from Dockery and Thompson, 2014, Environmental News, v. 11, no. 6, July 2014, p. 18-24).

The Eemian Stage of the Pleistocene was first recognized by Harting (1875) from boreholes in the area of Amersfoort, Netherlands, which contained a warm water marine molluscan assemblage that was different from the modern cold-water fauna of the North Sea. In North America, this stage is known as the Sangamonian Stage, or Sangamon Interglacial Stage, the last interglacial warm period before the present. The Sangamon Soil, a paleosol, underlies Wisconsinan loesses or tills in the water wells in northwestern Sangamon County, Illinois. At the Eemian's warmest peak about 125,000 years ago, the hippopotamus was distributed as far north as the Rhine and Thames rivers; trees grew as far north as Baffin Island in the Canadian Arctic Archipelago, and sea level peaked at 5.5 to 9 meters (18 to 29.5 feet) higher than today. This warm period is recorded in Antarctic ice cores (**figures 624-625**). Evidence for the Eemian sea-level highstand can be found in exposed fossil coral reefs worldwide throughout the tropics, including those of the Bahamas and Florida Keys. Evidence can also be found in marine terraces along stable continental coastal areas such as that of the Mississippi coast. This sea-level highstand occurred long before the advent of anthropogenic carbon dioxide and indicates that such a sea-level rise could occur in the future for reasons unrelated to carbon dioxide levels.

In an article published in the July 13, 2012, issue of *Science* entitled "Ice volume

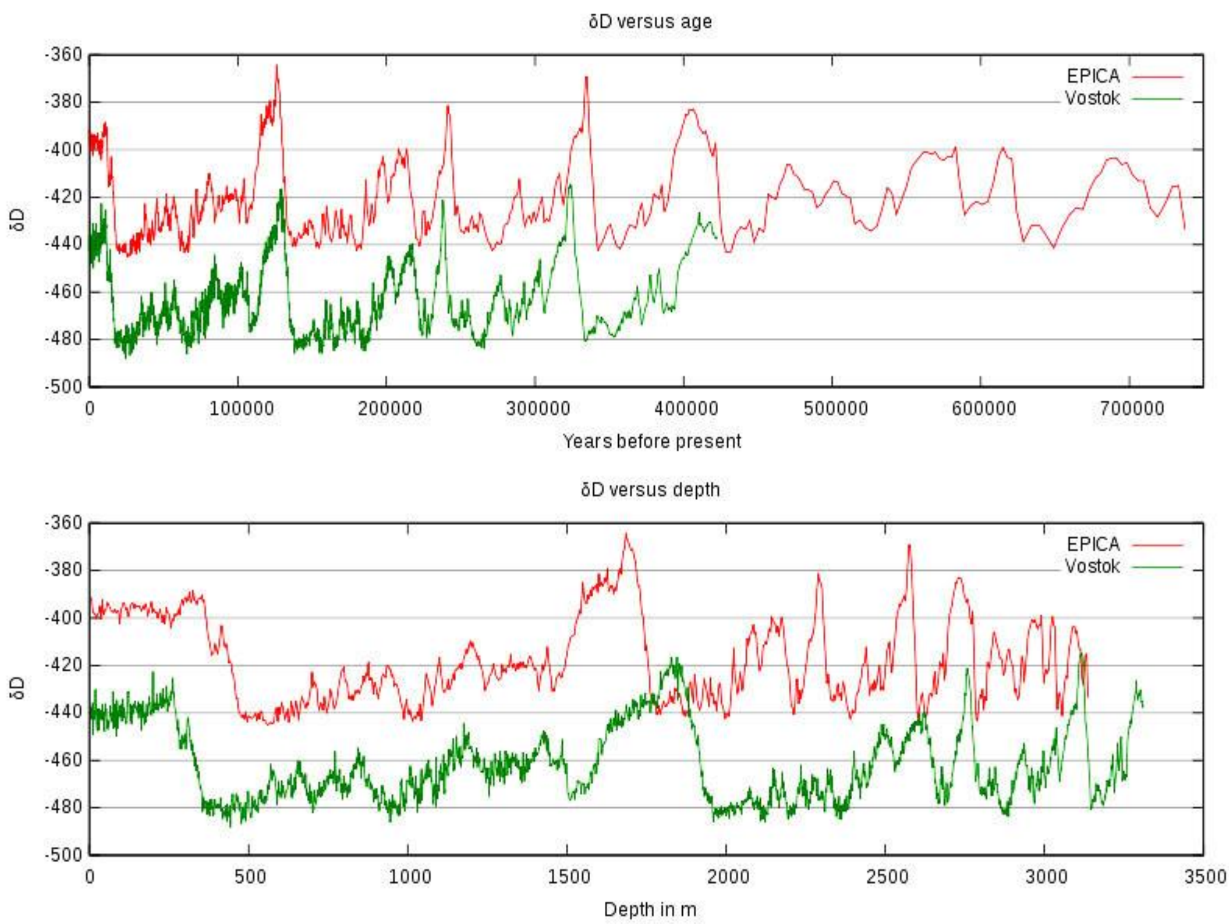


Figure 624. The Eemian Stage is between 1500 and 2000 meters in depth in the EPICA and Vostok ice cores, though a little offset due to problems in correlating depths to ages in the cores. The curves plot delta-deuterium against age and depth; the lower the negative delta-deuterium number, the higher the temperature (toward the top of the graph). In the EPICA curve (in red) the Eemian Stage was significantly warmer that the present interglacial period (from Wikipedia). Image 2487.

and sea level during the last interglacial," Dutton and Lambeck stated that "During the last interglacial period, ~125,000 years ago, sea level was at least several meters higher than at present, with substantial variability observed for peak sea level at geographically diverse sites." To account for such a rise in sea level would require both the collapse of the West Antarctic ice sheet and the Greenland ice sheet due to small changes in radiative forcing.

Figure 626 is a 1942 aerial photo-mosaic of the Mississippi Gulf Coast in portions of Harrison and Jackson counties. This early photo-mosaic predates much of the recent development and clearly shows beach ridges of Eemian/Sangamonian age, extending from Gulfport to Belle Fontaine. The fluctuating sea level of this period created first the Gulfport beach ridges, which trended southwest to northeast, and then the Biloxi beach ridges, which cut across the Gulfport beach ridges with more of a west-to-east trend. Stewart, Everett, and Marble, in an unpublished map (limited prints made in 2004), recognized 14 coast-parallel terraces in central and southern Mississippi. **Figure 627** is a portion of that map, showing the lower 4 terraces: Pamlico 1 at 1-10 feet above msl, Pamlico 2 at 11-30 feet above msl, Wade at 31-50 feet above msl, and Big Point at 51-90 feet above msl.

An island informally named here as the Sandhill Crane Island (an island pointed out to us by Lindsey Stewart) rests on the Wade Terrace; Big Ridge is a westward extension of that terrace with some beach-ridge highlands on its western end. Figure 6 is a lidar-data-derived relief map of the Mississippi coast in parts of Harrison and Jackson counties. This image shows the Gulfport and Biloxi beach ridges in great detail and Big Ridge and the Wade Terrace highlands associated with Sandhill Crane Island, which diverges from Big Ridge in a westerly direction. Dr. Ervin Otvos (1975)

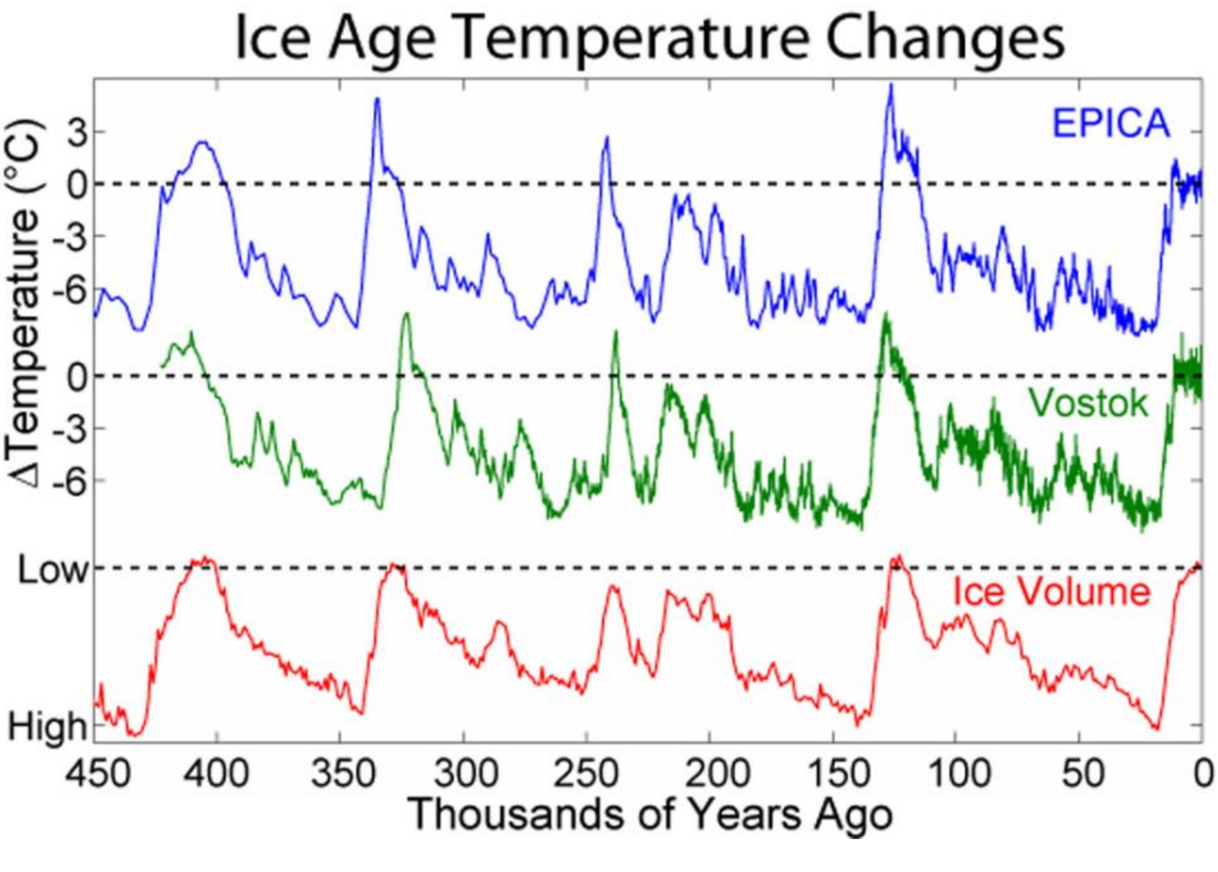


Figure 625. Antarctic temperature changes during the last several glacial/interglacial cycles of the present ice age and a comparison of temperature and ice volume. The upper two curves show local changes in temperature at two sites in Antarctica as derived from deuterium isotopic measurements on ice cores. The warm peak of the Eemian Stage is at 125,000 years (Wikipedia). Image 2488.

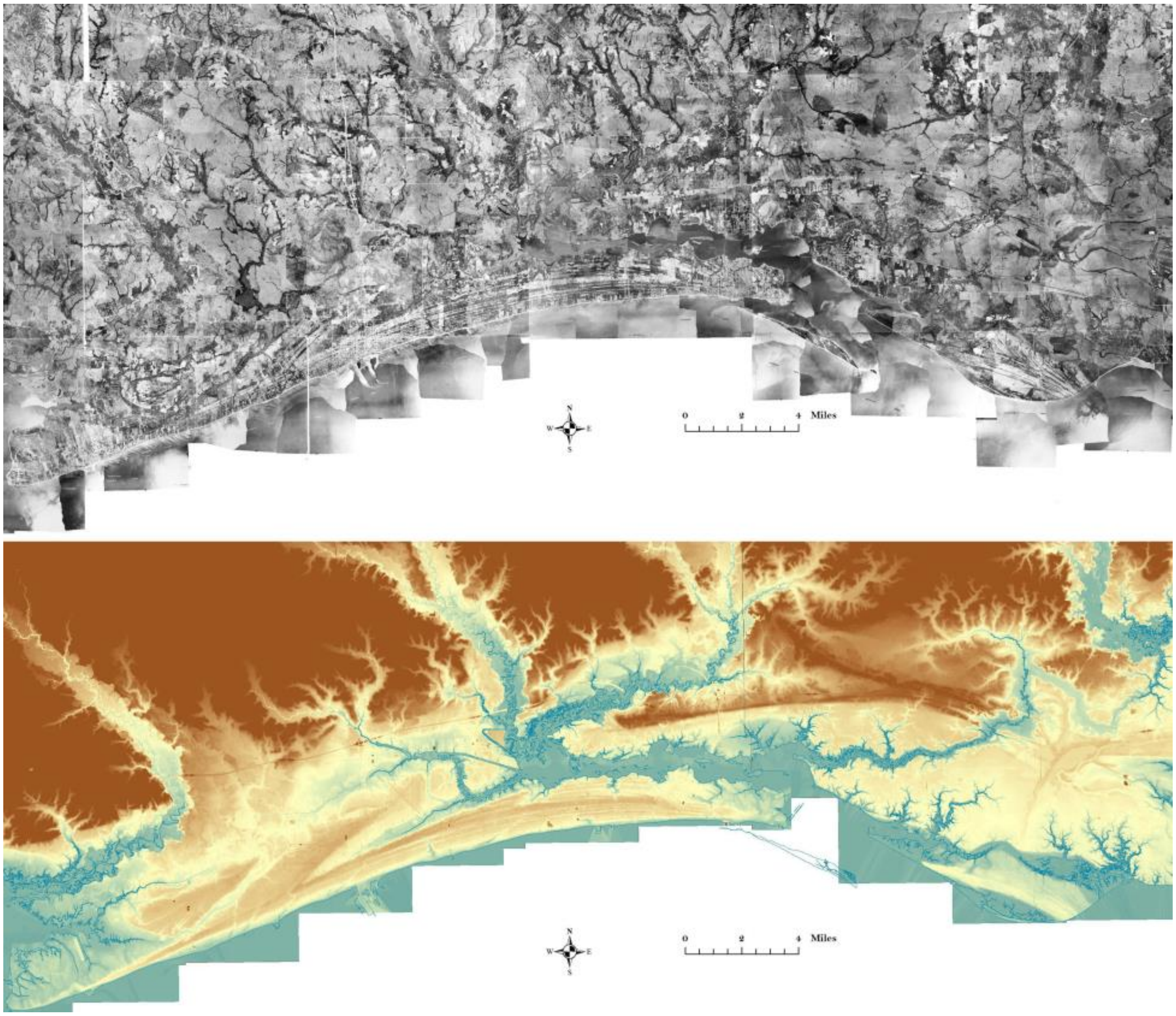


Figure 626. Top: 1942 areal photo-mosaic of the Mississippi Gulf Coast in portions of Harrison and Jackson counties. Beach ridges from Eemian/Sangamonian Stage can be seen at Belle Fontaine on the east and along the Biloxi coast where they cut across older southwest-northeast-trending ridges at Gulfport on the west. The Biloxi beach ridges deflect the Biloxi River from a north-south, to a west-to-east course (image from the Mississippi Departent of Marine Resources). Bottm: Lidar-data-derived relief map of the Mississippi coast in parts of Harrison and Jackson counties, showing the Gulfport and Biloxi beach ridges and Big Ridge and the Sandhill Crane islands, which converge to the east near their common source. Sequence of events: (1) an old course of the Pascagoula River provided sand to east-to-west longshore currents, creating Sandhill Crane Island and then (2) Big Ridge, (3) the Biloxi River provided sand for the Gulfport beach ridges and then (4) the Biloxi beach ridges, and (5) a later course of the Pascagoula River, visible in high-standing levee deposits, created the Belle Fontaine delta, which was reworked into the Belle Fontaine beach ridges. Image 2495.

recognized the Gulfport and Biloxi beach ridges to be of Sangamon age and named these structures the "Gulfport Formation." Underlying this formation, Otvos described a fossiliferous marine unit of Sangamon age, which he named the "Biloxi Formation."

Figure 628 shows the Point Clear delta of the Pearl River, where truncation of levee deposits associated with an abandoned course of the Pearl River in Hancock County formed barrier spits east and west. Lower on the delta plain are other southeast-northwest trending islands.

Figure 629 is a series of 3 images, which, from top to bottom, gives the coastline after sea-level rises of 16 feet, 25 feet, and 47 feet. At a sea-level rise of 16 feet, the crests of beach ridges at Belle Fontaine appear as barrier islands. At a sea-level rise of 25 feet, the crests of the Gulfport and Biloxi beach ridges

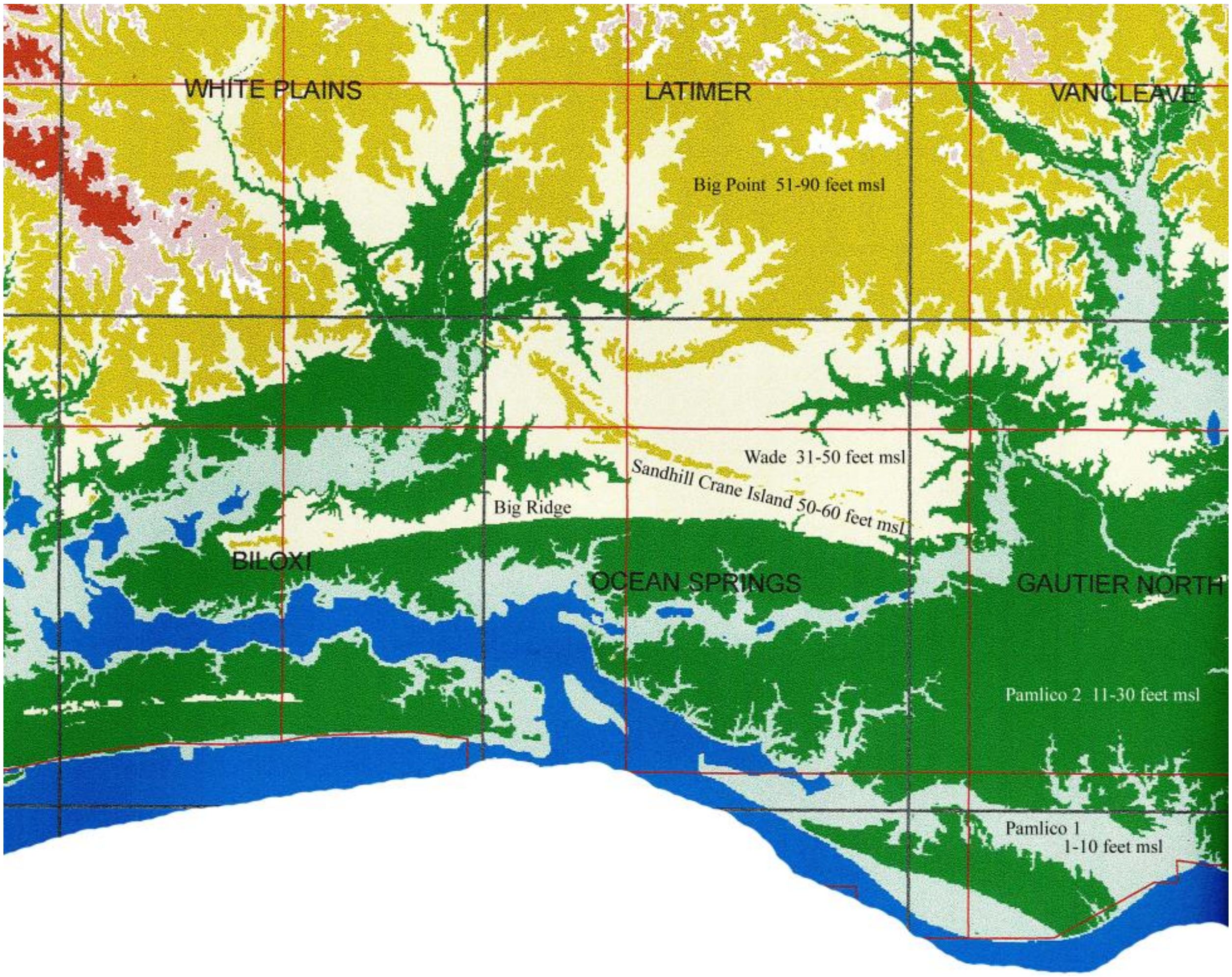


Figure 627. Coastal marine terraces as mapped by elevation data, unpublished map by Stewart, Everett, and Marble (limited prints made in 2004). From lowest to highest elevation, these include Pamlico 1 from 1-10 feet above msl, Pamlico 2 from 11-30 feet, Wade from 31-50 feet, and Big Point from 51-90 feet. Extending westward from the Wade Terrace is Big Ridge with a wave-cut southern margin; perched on the Wade Terrace is the Sandhill Crane Island from 50-60 feet. Image 2491.

appear as barrier islands, and the western end of Big Ridge appears as a spit along a wave-cut shoreline. Islands to the east are levee deposits of an old course of the Pascagoula River, which fed the Belle Fontaine delta. At a sea-level rise of 47 feet, Sandhill Crane Island is visible along with a spit behind the island, extending westward from the mainland, and a barrier island is visible on the western end of Big Ridge. Also at this highstand, irregularities in the coastline between embayed river and stream valleys smooth out to form a linear shoreline.

The morphology of Mississippi Gulf Coast landforms, created during the Eemian/Sangamon Interglacial period, gives evidence of sea-level rises of: (1) a few feet for the beach ridges on Belle Fontaine in Jackson County and the islands on the Clear Point delta of the Pearl River in Hancock County, (2) over 20 feet for the Gulfport and Biloxi beach ridges in Harrison and Jackson counties, and (3) as high as 47 feet for Big Ridge and Sandhill Crane Island in Harrison and Jackson counties. Yet this “run-away” event in global warming did not prevent the subsequent 100,000-year-long ice age known as the Wisconsin Glacial Episode, which reached its maximum extent only 18,000 years ago and dropped sea level as much as 115 meters, or 377 feet, below present sea level.

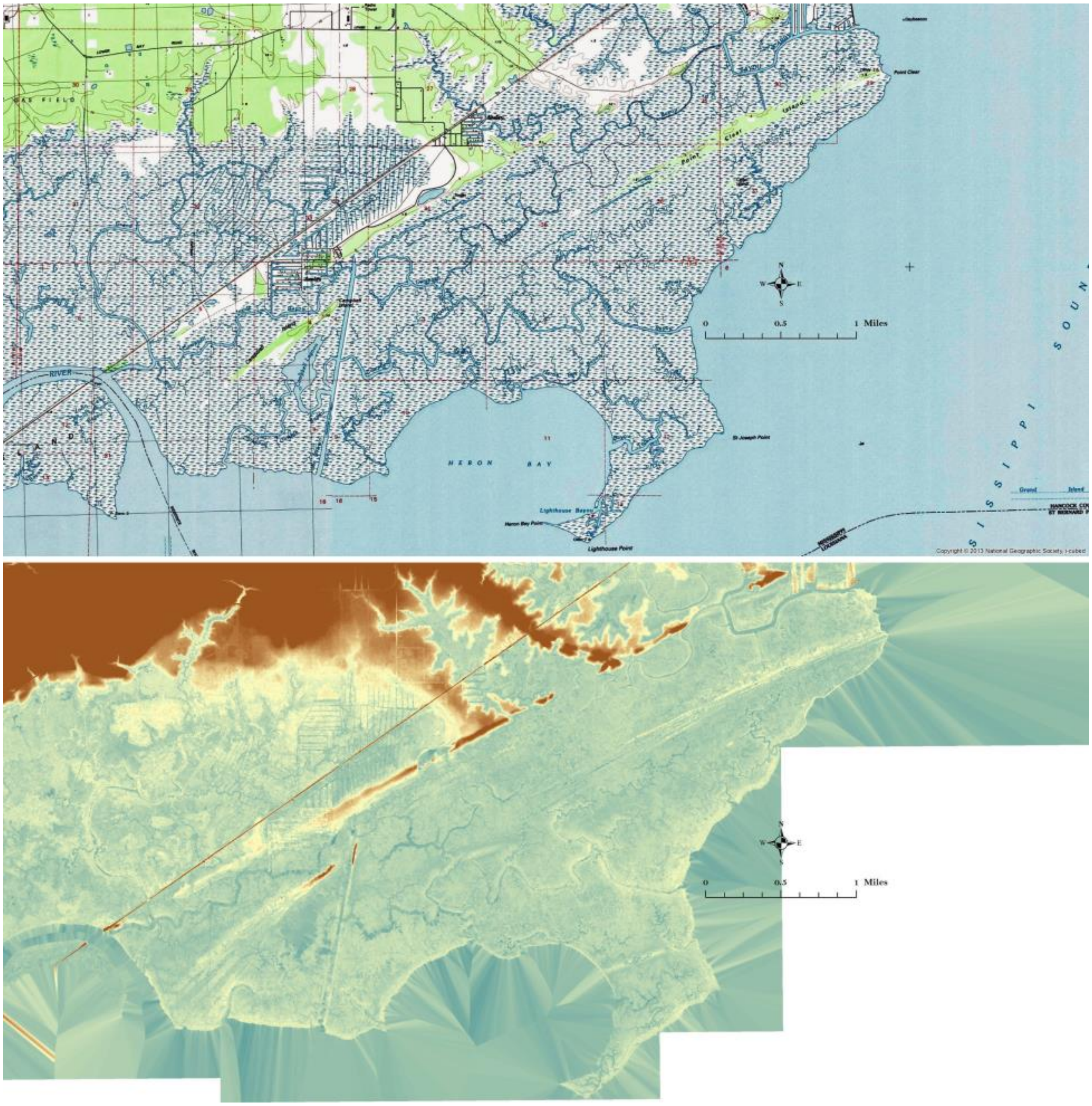


Figure 628. Shoreline prominence in Hancock County at the Point Clear delta of the Pearl River; high ground in brown on the lidar image (bottom) shows the southeastern course of the river's levee deposits, truncated to form southwest-northeast trending barrier islands. Lower on the delta plain are Campbell Island to the west and Point Clear Island to the east (Point Clear Topographic map at top). Image 2494.

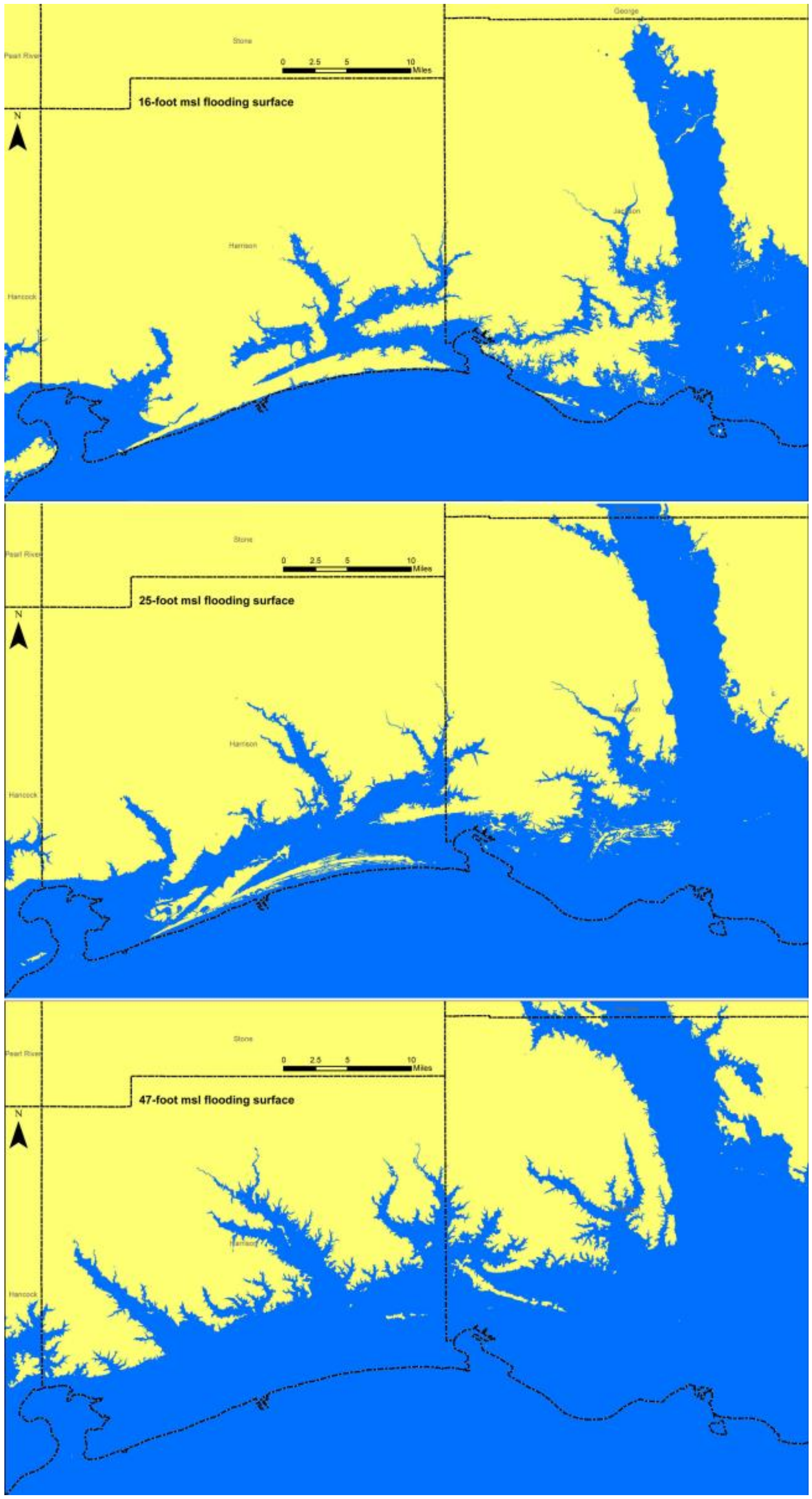


Figure 629. From top to bottom, sea-level rises of 16, 25, and 47 feet show, repectively, the island crests of the (1) Belle Fontaine and (2) Gulfport-Biloxi beach ridges, and (3) Sandhill Crane Island. Image 2493.

THE NEW ORLEANS BARRIER SAND TREND AND KATRINA (from Dockery and Nelson, 2010, Environmental News, v. 7, no. 7, September 2010, p. 22-26.

August 29, 2015, marked the tenth anniversary of the landfall of Hurricane Katrina on the Mississippi Gulf Coast and the destruction of much of the Mississippi coastal area and the destruction of large sections of a major American city, New Orleans. Though initial news reports suggested that New Orleans had dodged another bullet, the city was doomed to flood from two directions, one from a storm surge on the Intracoastal Waterway to the east and a second from a storm surge from Lake Pontchartrain to the north. The following is a geological explanation as to why the London Avenue Canal leading to Lake Pontchartrain failed. This explanation begins with the New Orleans area as it was 5,000 years ago.

A rise in sea level after the Wisconsin Ice Age brought the retreating Gulf Coast shoreline to the New Orleans area about 5,000 years ago. At this time an east-west spit, extending from the mouth of the Pearl River, grew westward to form a barrier island at present-day New Orleans. This barrier island sand body is variously named the "Pine Island Barrier Spit" or the "New Orleans Barrier Trend" and is now buried beneath the City of New Orleans. Covering the barrier sands are more recent fluvial and deltaic sediments. As shown in **Figure 630**, the spit underlies the southern shore of Lake Pontchartrain, where it is encountered on occasion during construction work and excavations.

Evidence that the New Orleans Barrier Trend was a barrier island much like those off the coast of Mississippi today came from the dredging of the Intracoastal Waterway on the east side of the city in September of 1975. Here dredge work cut through sands seaward of the island and brought up an abundance of seashells similar to those presently living in the northern Gulf of Mexico. At the time, I (Dockery) was a graduate student at Tulane

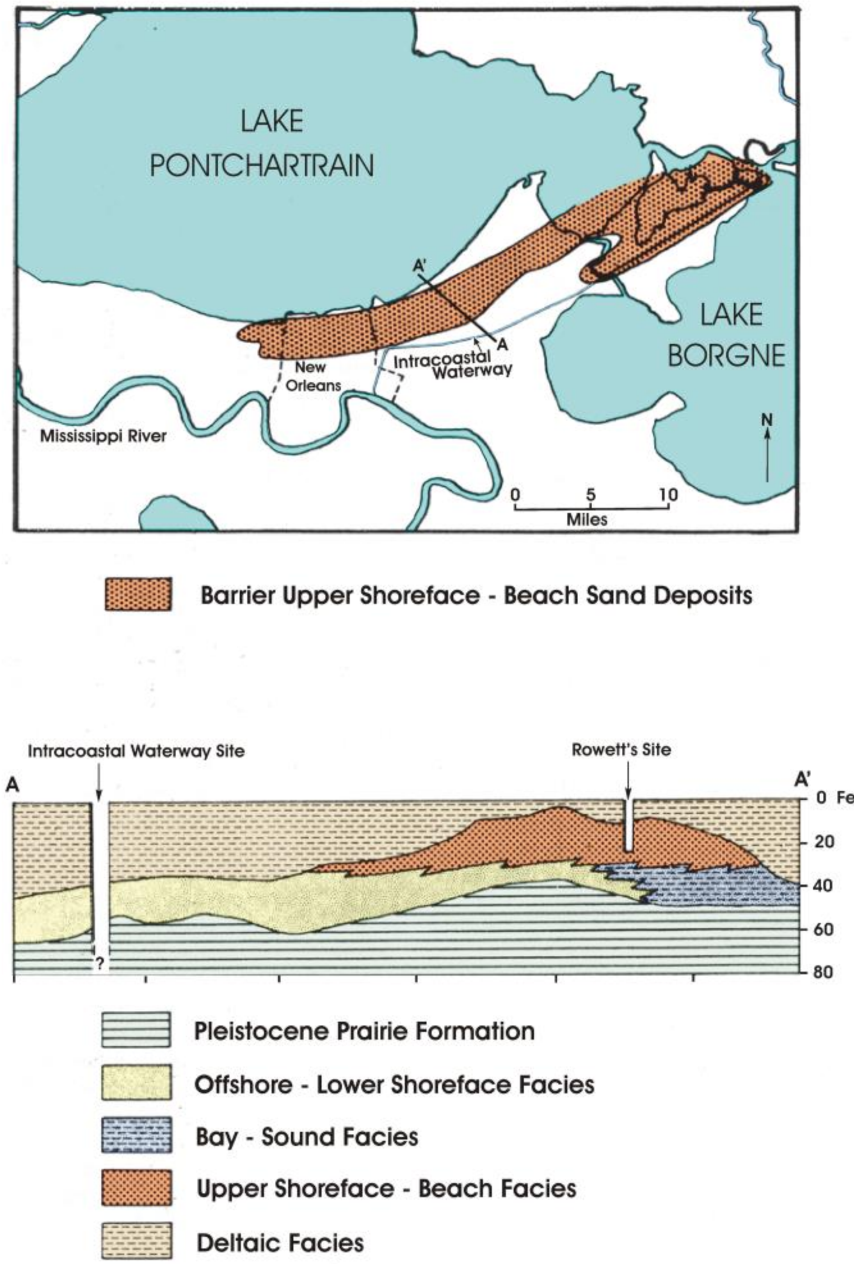


Figure 630. Distribution of upper shoreface-beach sands in the New Orleans Barrier Trend and cross section of the barrier facies with two locations where seashells were found (figure from the publication of Hollander and Dockery, 1977). Image 1805.

Figure 631. Tulane students collecting shells dredged from the Intracoastal Waterway east of New Orleans. Eileen Hollander is at far left. Picture (slide #10-15) taken in April of 1976. Image 1807.

Figure 632. Seashells in dredge piles along the Intraoastal Waterway east of New Orleans. Picture (slide #10-10) taken in April of 1976. Image 1808.

Figure 633. Shell of the large whelk Busycon contrarium (Conrad, 1840) dredged from the Intracoastal Waterway east of New Orleans. Picture (digital) taken on January 27, 2010. Image 1809.

Figure 634. Katrina storm surge with high waves topping the levee on the north side of the Intracoastal Waterway right under the Paris Road/Highway 47 bridge. Picture taken by someone at the Entergy Power Plant in the early morning of August 29, 2005. Image 1810.

University and was teaching the lab for an Invertebrate Paleontology class. The students were assigned a class project to salvage fossil shells dredged from the Intracoastal Waterway (**figures 631-632**). Another Tulane graduate student and biology major, Eileen Hollander, worked with me to publish and illustrate some 95 molluscan species from the site. One particularly large shell that survived the passage through the dredge pump was a large whelk of the species *Busycon contrarium* (**Figure 633**). The species was named *contrarium* because of the shell's left-handed coil rather than a right-handed one as is common for most gastropod (snail) shells.

The New Orleans Barrier Trend proved to be one factor that contributed to levee failures during Hurricane Katrina's storm surge. When Hurricane Katrina struck the Gulf Coast on Monday August 29, 2005, NOAA's buoy about 50 miles off the mouth of the Mississippi River recorded 40-foot waves at 3:00 AM; two hours later these waves reached a height of 46 feet. Katrina's storm surge of some 18 feet, two feet higher than the levee tops in eastern New Orleans, arrived in the city from the Gulf of Mexico by way of the Intracoastal Waterway (**Figure 634**), overtopping the waterway's levees along the way. Levees along the New Orleans Industrial Canal connecting the Mississippi River and Lake Pontchartrain were overtopped and breached by 7:00 AM, flooding areas north of the French Quarter. A catastrophic failure of the canal's eastern floodwall and levee devastated the city's Lower Ninth Ward.

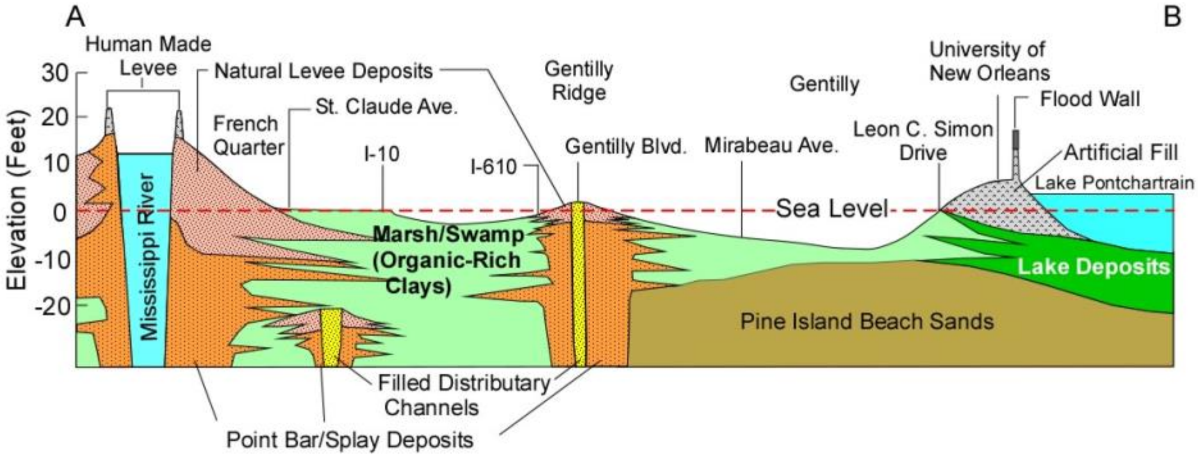


Figure 635. Geologic and topographic profile across New Orleans, showing Gentilly Ridge (from Nelson and Leclair, 2006). Image 1811.

When Hurricane Katrina made landfall on the Mississippi Gulf coast, many New Orleans residents awoke that morning thinking that the city had dodged another hurricane "bullet." However, by 8:00 AM, New Orleans Mayor Nagin told the audience of NBC's *Today Show* that the city's levees had been breached and that the city was flooding. Soon after this announcement and as the hurricane moved inland, the storm surge from Lake Pontchartrain entered canals designed to drain the city's rainwater, resulting in the catastrophic failure of levees at two sites on the London Avenue Canal. These sites were not overtopped but failed as high water piped through sands of the New Orleans Barrier Trend and undermined the levee's foundations. **Figure 635** shows the presence of the barrier sand, labeled the "Pine Island/Beach Sands," under the flood wall along the southern shore of Lake Pontchartrain. **Figure 636** shows how the storm surge seeped through the barrier sands to undermine the floodwall at the south breach on the London Avenue Canal. Homes near the breach were extensively damaged and filled with sand in a type of flood deposit called a crevasse splay. The London Avenue Canal crevasse splay buried cars and yards under some 26,380 cubic meters of sand and gravel-size clay balls (Nelson and Leclair, Katrina's unique splay deposits in a New Orleans neighborhood: *GSA Today*, September 2006, p. 4-10). These deposits also contained seashells, like those collected by Tulane students from the Intracoastal Waterway dredge piles (**Figure 637**). Among the splay-deposit shells was the large clam *Dinocardium robustum*, a clam common in the dredge piles and common today along the seaward side of Mississippi's barrier islands, especially the southern shore of Ship Island.

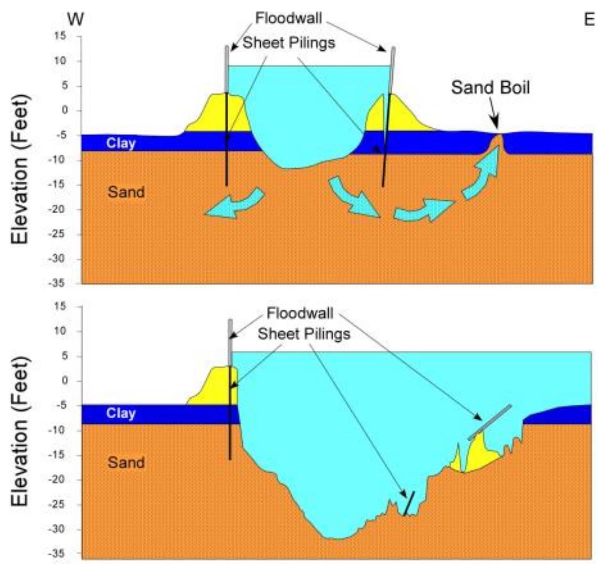


Figure 636. Seepage and piping through the New Orleans barrier sand at the London Avenue Canal south breach. Image 1812.

Figure 637. Invertebrate Paleontology preparing for a field trip to collect seashells from the Intracoastal Waterway dredge piles in April of 1976. Image 1806.

GEOLOGY, GROUNDWATER, AND MUSTARD GAS ON HORN ISLAND

Horn Island, Jackson County, Mississippi, shelters the Mississippi Sound to its north and is part of the Gulf Islands National Seashore. It is home to varied wildlife, including alligators, ospreys (**Figure 638**), pelicans, ducks, tern, herons, and other migratory birds and is a favorite boating destination for those living on the Mississippi Gulf Coast. It was also a favorite resort for artist Walter Anderson, who spent the years between 1946 and 1965 drawing and painting the island's landscapes and wildlife.

Mississippi's barrier islands formed between 5,000 and 3,500 years ago when the rate of post-Pleistocene sea-level rise slowed, and when the coastline was located approximately where it is today. Dear, Round, and eastern Dauphin islands were Pleistocene high grounds that were surround by rising Gulf waters. Eastern Dauphin, Petit Bois, Horn, Ship and Cat islands were formed by the westward long-shore transport of sand from Dauphin Island at the mouth of Mobil Bay. Mobil Bay sands were derived from an Appalachian Piedmont source and contained valuable heavy mineral deposits as seen in the dark bands within Horn Island beach sands (**Figure 639**). Horn Island has shifted its location over historical times as shown in **Figure 640**.

Figure 638. Osprey nest on Horn Island. Picture by Richard Ball, June 25, 2013. Image 2497.

Figure 639. U.S. Army Corp of Engineers employee pointing out dark bands of heavy minerals in the Horn Island beach deposits. Picture by Richard Ball, June 25, 2013. Image 2496.

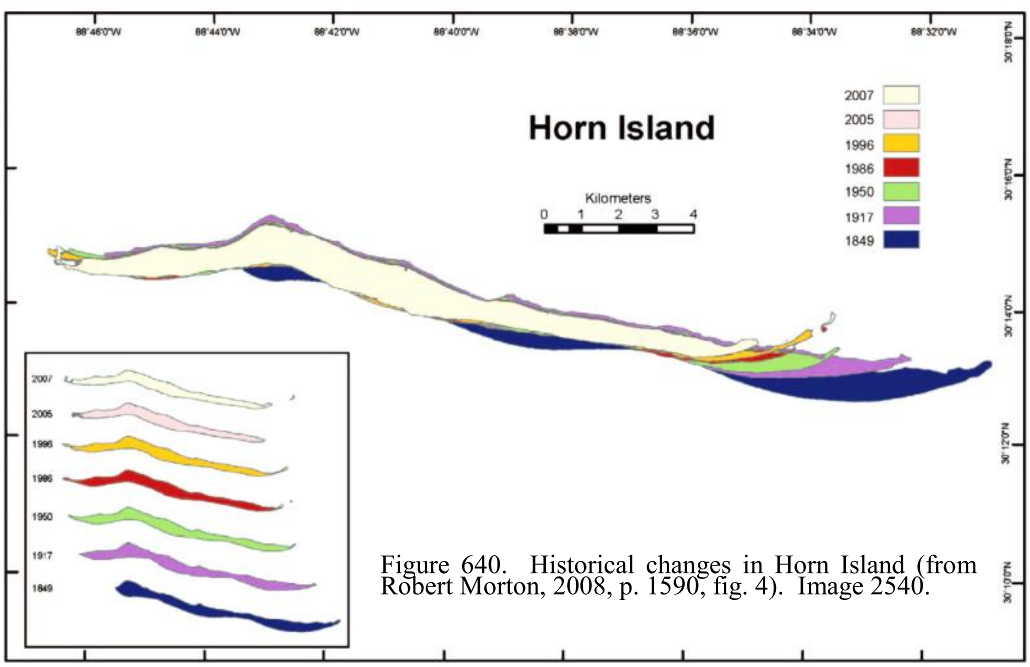


Figure 640. Historical changes in Horn Island (from Robert Morton, 2008, p. 1590, fig. 4). Image 2540.

Figure 641. Remains of Department of War buildings on Horn Island used to test biological toxins from 1943-1944. Picture taken by Richard Ball on June 25, 2013. Image 2541.

Figure 642. Horn Island from Google Map: Google posted location (left marker) where "according to records from the National Park Service mustard gas may have been disposed of in Chimney Lagoon on Horn Island." Chimney lagoon is marked at right. Image 2542.

In June of 2012, British Petroleum asked the National Park Service (NPS) to provide a list of potential chemical and biological hazards on Horn Island before the company deployed cleanup crews in response to the Deepwater Horizon oil spill. One reason for this unusual caution was an area on the north side of the island known as the Chimney, which was operated by the Department of War to test biological toxins from 1943-1944 (**Figure 641**). Another reason was due to various reports of mustard gas disposal on the island. The Department of Nuclear Engineering, University of California, Berkley, posted (January 14, 2012) an article with reports from Army records that "124 leaking German mustard gas bombs were tossed in the Gulf of Mexico off Horn Island in Mississippi in 1946 from a barge that returned to port a few hours later." NPS contracted with an environment services firm to conduct a preliminary site assessment and inspection and to test for multiple contaminants. This led to the discovery of contaminants and a list of potential contaminants from a review of the site's historical records. On August 17, 2012, National Seashore Superintendent Dan Brown announced that part of Horn Island was closed to the public effective immediately because of the discovery of hazardous materials (Gulf Islands Park News). In particular: "A preliminary test also indicated the possible presence of a chemical agent known commonly as mustard gas." The Superintendent added that based on an initial records search "we have reason to believe that some containers of mustard gas may have been deposited in the Island's Big Lagoon" (also called the Chimney Lagoon) (**Figure 642**).

Mustard gas is a liquid under normal conditions that is heavier than water and which doesn't mix with water. It will sink to the bottom of water-bearing sands on and around Horn Island unless it is absorbed by mats of organic material within the island sands. In 1994, The Office of Geology, in cooperation with the U.S. Geological survey, published a volume entitled "Final Report, Mississippi Coastal Geology and Regional Marine Study 1990-1994." This report contained a section on the "Geologic Framework of Coastal Harrison County and Mississippi Sound" that reconstructed the Pleistocene to Holocene geologic framework based on a compilation of 304 cores and drill holes. Data used in the report can be found on the Office of Geology website, which shows the location of cores and core sample records in the Mississippi Sound and offshore of the barrier islands.

Figure 643 is a geologic cross section of Horn Island based on core descriptions by Ervin Otvos. The dotted line through the cross section marks the Pleistocene-Holocene boundary (as picked by Otvos); this line generally separates non-marine sediments below from marine sediments above. During the last glacial maximum some 18,000 years ago, sea level was much lower than today, and the Horn Island area was dry land. As the ice began to melt, sea level rose steadily over a period of several thousand years until it reached the present coastline. Due to the slow rise, the Horn Island area was still dry in early Holocene time as determined by the radiocarbon age of 9,470±90 years old for a peat deposit in a core at a depth of 76.7 feet beneath the island. The Pleistocene-Holocene boundary has a radiocarbon age of 10,000 years old, so the uppermost Pleistocene in **Figure 643** may be of early

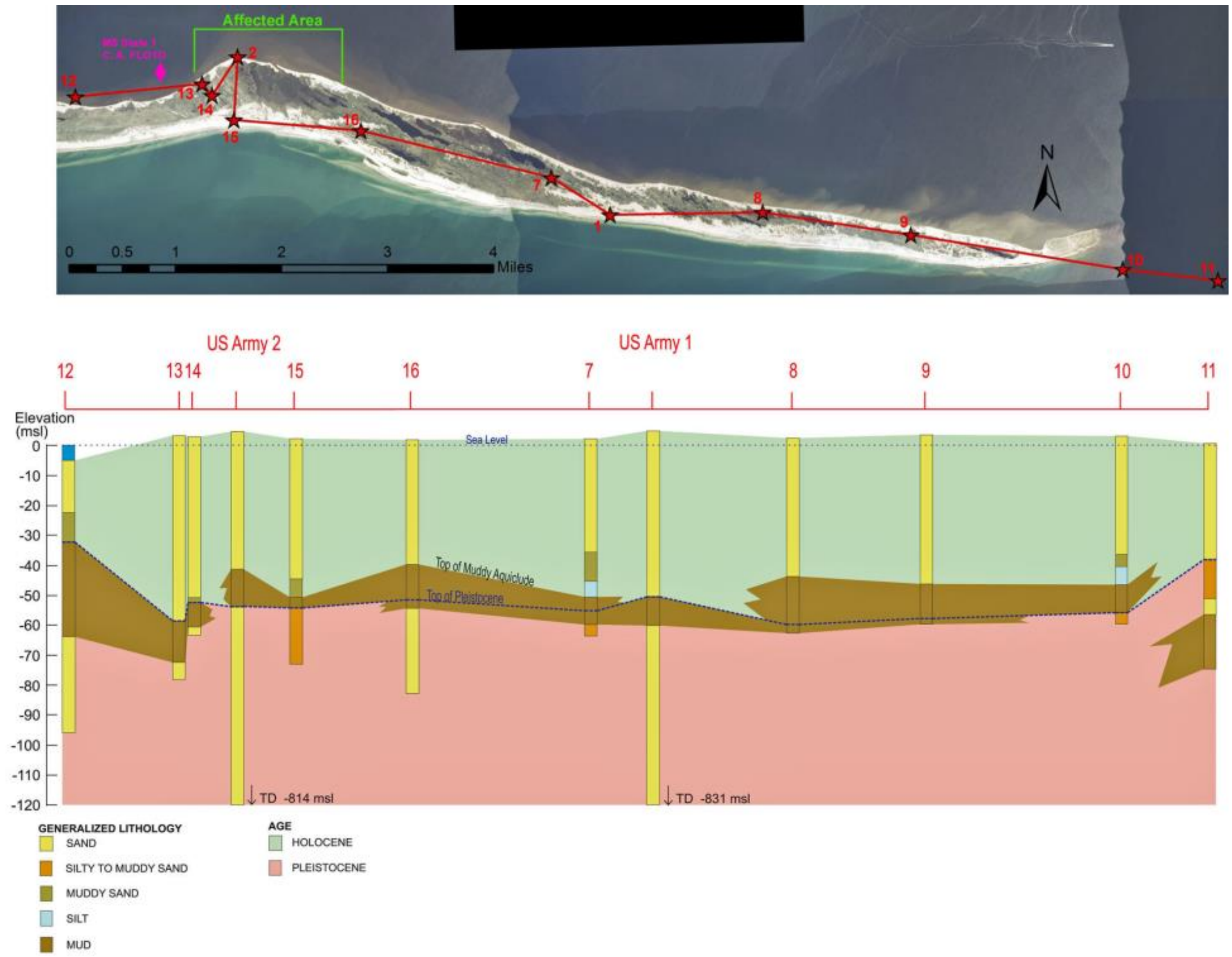


Figure 643. East-west cross section of Horn Island based on core descriptions by Otvos. Pleistocene sands are in pink; Holocene sands are in green. Clay units at the top of the Pleistocene and the base of the Holocene are in brown. A dotted line marks the top of the Pleistocene. Possible gaps in the clay confining layer occur between well 14 and U.S. Army well 2 at the terminus of Pleistocene clay to the west and Holocene clay to the east and between wells 10 and 11 at the terminus of Holocene clay to the west and Pleistocene clay to the east. Image 2543.

Holocene age. Non-marine fluvial and alluvial sands attributed to the Pleistocene are shown in pink on the cross section, while Holocene marine sands are shown in green.

A clay bed frequently occurs at the base of the Holocene section below the island. Clay beds at the top of the Pleistocene section do not correlate with those at the base of the Holocene section as the two intervals are not depositionally related. Where present, these clays form an aquitard that would impede the downward migration of mustard gas, thus protecting groundwater supplies. Where clay beds are absent, mustard gas can migrate from Holocene to Pleistocene sands. Pleistocene sands of the cross section are regionally correlated with the Pamlico Formation, a formation that continues to the mainland, where it forms a coastal terrace with a maximum elevation of 25 feet above mean sea level. Two possible "sand chimneys" allowing a downward migration occur between well 14 and the US Army 2 well and between wells 10 and 11. Other possible avenues of contamination are the well bores of the MS State #1 Floto gas exploration well and US Army water wells 1 and 2 drilled to a depth of 831 and 814 feet below sea level.

Freshwater aquifer sands are present below Horn Island in the Graham Ferry aquifer. This aquifer is confined by fine-grained beds above and is under an artesian pressure that has historically produced flowing wells at the surface (**Figure 644**). Confining beds and artesian pressure make it less likely that groundwater resources in the Graham Ferry will be adversely affected by surface contaminants. On June 25, 2013, Army contractors (**Figure 645**) resampled the area of the first preliminary positive test for mustard gas and found no contamination.

Figure 644. Flowing artesian well in the Graham Ferry aquifer at Ship Island as illustrated by Lowe (1915) in Mississippi Geological Survey Bulletin 12, page 113, figure 10. Image 2544.

Figure 645. Army contractors sampling for mustard gas on Horn Island. Picture was taken by Richard Ball on June 25, 2013. Image 2545.

CHAPTER 15. EMERGENY MANAGEMENT

Tornadoes. One of the greatest natural disasters in Mississippi history was the "Great Natchez Tornado," the second deadliest tornado in U. S. history, killing more than 317 people and injuring 109. The tornado formed shortly after 1:00 p.m. on May 7, 1840, in Concordia Parish, Louisiana, reportedly killing hundreds there and devastating the village of Vidalia. The storm then moved northeast along the Mississippi River stripping forests on both banks. At Natchez Under the Hill the tornado made an almost complete devastation of dwelling, stores, steamboats, and flatboats, tossing 60 flatboats into the river, drowning crews and passengers, and picked up others and throwing them onto the land. The storm then moved into the town of Natchez slamming the central and northern portions of the city. At Natchez, 48 people were killed on land, and 269 were killed on the river.

Lloyd's Steamboat Directory, published in 1856, included a story about the Natchez tornado. It noted that: "A tax had recently been laid on flat-boats at Vicksburg, on which account many of them had dropped down to Natchez, so that there was an unusually large number of those boats collected at the last-named city at the time of the tornado." The steamboat *Hinds* was sunk and swept down to Baton Rouge, where it was found with 51 bodies aboard. The steamboat *Prairie* had just arrived from St. Louis with a load of lead. It was stripped of structures above deck, leaving no survivors. The floating hotel and grocery store boat named the *Mississippian* was sunk, and the somewhat sheltered H. Laurence was badly damaged but not sunk. Of the 120 flatboats at the Natchez landing that day, all but four were lost along with their crews.

The 1936 Tupelo-Gainesville Tornado Outbreak in the southeastern United States from April 5-6, was the second deadliest in U.S. history, killing 454 people of which 419 were killed in just two tornadoes. Over 216 people were killed in the Tupelo area with another 700 injured. Many well built structures were leveled and swept away on the west side of the city. Mississippi Geological Survey Bulletin 31, entitled *The Tupelo Tornado*, by Dr. William Clifford Morse, 1936, was written, "in hope that it will lead to the building of better and safer cities." Morse illustrated the tornado's damage in Tupelo, which struck at about 9:00 p.m. the Sunday evening of April 5, 1936. He noted that there was, "selective destruction … not due exclusively to the tornado, but partly to man's own imperfect building."

Figure 646. NOAA Weather Radio coverage, transmitters in Mississippi. Image 2546.

In a more recent Tupelo tornado on May 4, 2014, many Tupelo residents said that a weatherman saved their lives. FOX6 Now: put it this way: "When severe weather raced through Tupelo, Mississippi, this week, one meteorologist didn't mess around. With a tornado bearing down on his television station, he ordered everyone in the studio to get to safety." Chief meteorologist at Tupelo station WTVA yelled for his staff to take cover, "Basement. Now...let's go!" Viewers watching the program were shocked by the rush to safety in the studio and did the same.

Television and radio alerts have saved many lives in Mississippi. National Oceanic and Atmospheric Administration (NOAA) Weather Radio provides continuous broadcasts direct from local offices of the National Weather Service. NOAA Weather Radio transmitters serve Mississippi through a number sites as shown in **Figure 646**. Regular broadcasts are tailored to the needs of those in the listening area of the local transmitter. A special tone automatically triggers weather ra-

Figure 647. The floor of a moblie home west of Highway 49 in Yazoo City impaled on the splintered trunk of a tree. Pictures were taken on April 25, 2010. Image 2547.

Figure 648. Left, behind the rubble of an old car dealership and broken trees is a modest house still standing (though the furniture was sucked out by the storm) west of Highway 49 in Yazoo City. Right, behind the house at left is a car in the eye of the strorm untouched and an igloo dog house unmoved. Pictures were taken on April 25, 2010. Image 2548.

dio receivers to alert listeners of dangerous weather situations.

On a Saturday morning, the usually monotone weather report on Weather Radio in Jackson, Mississippi, repeats messages such as, "Showers likely and a chance of thunderstorms. Waters a moderate chop, with choppiest waters in the upper reservoir." But, on the Saturday morning of April 25, 2010, the tone was different. A panicked announcer was frantically calling for Yazoo City residents to find shelter in a safe place immediately. A wedge tornado was on the ground headed for the city!

The tornado, estimated to be a mile wide, began in the early morning hours of April 24 in Louisiana destroying power poles west of Tallulah. It crossed Interstate 20 and destroyed a chemical plant in the Omega community. Crossing the Mississippi River it destroyed homes on the north side of Eagle Lake and then mowed down trees in the Delta Nation Forest in Issaquena and Sharkey Counties before causing significant damage to homes northwest of Satartia. The storm crossed Highway 3 and moved through rural areas southwest of Yazoo City. All of this information was available to Jackson Weather Radio, thus the urgent call to take cover and for those in mobile homes to find a safer place.

The Yazoo City tornado killed ten people and injured 146. It was the state's worse natural disaster since Hurricane Katrina in 2005 with wind speeds up to 170 miles per hour, a maximum width of 1.75 miles (a rec-

Figure 649. Tornado track across north Jackson on April 4, 2008. Image 2549.

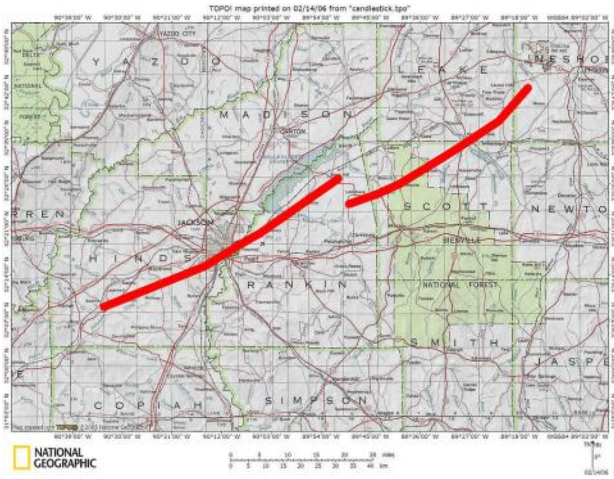


Figure 650. Revised tornado track for the Candlestick Park Tornado on March 3, 1966, shows tw separate tornadoes. Fifty eight people were killed in five counties along this course. Image 2550.

ord for the state), and a path 140.25 miles, ending north of Sturgis, Mississippi. The storm was on the ground for nearly 3 hours. **Figure 647** shows the floor of a mobile home in Yazoo City impaled on a shredded tree trunk. **Figure 648**, at right, shows a car and dog house untouched in the midst of the devastation.

A modest size tornado that crossed north Jackson on April 4, 2008, was awarded $3.4 million in federal funding for debris removal (**Figure 649**). The tornado hit as 1,500 students from around the state were participating in a Children's Educational Fair at the State Agricultural Museum not far from the storm tack. Just north of the museum, hail-laden wind damaged 75 new car at Watson Quality Ford, blowing the windows out of most of them. The damage estimate from this storm was said to rank as Jackson's third most costly disaster since the Pearl River Flood in 1979 and the burning of the city by Sherman in 1863.

The most famous tornado in the Capitol City was the violent F5 Candlestick Park Tornado on March 3, 1966, which leveled the Candlestick Park shopping center with people inside, twelve of which were killed. The storm began is southwestern rural Hinds County around 4:00 p.m. and continued a 202.5 mile track to Tuscaloosa County, Alabama (one of the longest paths ever recorded), dissipating at 7:45 p.m. The death toll of the storm was 58 with 19 killed in Hinds County, 5 in Rankin County, 6 in Leake County, 1 in Neshoba County, and 1 in Pickens County, Alabama. The Jackson, Mississippi, branch of the National Weather Service and meteorologist Thomas P. Grazulis reassessed historical data on the storm and concluded there were two tornadoes responsible for the long storm track, the second tornado forming when the first one dissipated (**Figure 650**). However, this reassessment leaves a gap in the track over Neshoba County where one person was killed. The National Climatic Data Center officially records only one tornado as responsible for the track.

A few years after the Candlestick Park Tornado, on January 23, 1969, an early morning tornado was detected at 5:45 a.m. near Hazlehurst, Mississippi. The storm struck homes near a lumber pond, dumping several people in the pond. They were listed as missing until the pond was drained and their bodies were recovered. The storm demolished about 20 homes and damaged 30 to 35 homes in Hazlehurst (**Figure 651**). Lewis (Jiggs) and Irene Ashley were standing between their bed and bedroom window when the tornado hit their mobile home. Lewis grabbed his wife's shoulders, but she was sucked from his grasp, sending Lewis backward across the bed. The body of his wife was found two miles from their home. The tornado killed 10 people in Copiah County, 11 in Simpson County, and 6 in Smith County (**Figure 652**).

The Jackson Metro area was given warning on the morning of April 15, 2011, as sirens sound and Jackson residents sought cover. The Clinton Tornado touched down south of Interstate 20 at the Springridge Road interchange, where storm chasers focused their camera on the funnel cloud around 10:57 a.m. as it traveled northeast. The video showed the damage as the storm took the roof off the Bank Plus

Figure 651. United Press International photograph of tornado damage in Hazlehurst on January 23, 1969. Image 2567.

building and threw cars onto the interstate. Inside the bank, one employee recounted the staff huddled in a hallway, and her ears popping before the roof blew off and then hail hitting her head. The storm did much damage in Clinton's Lakeside Subdivision before thread-

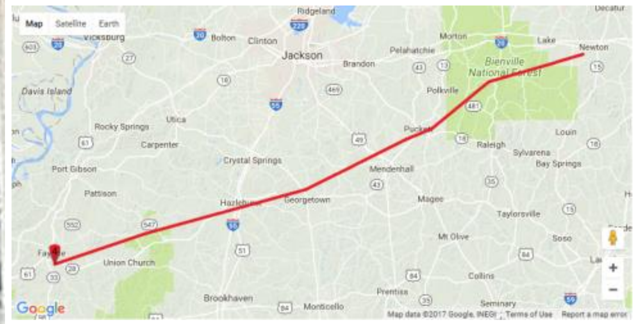


Figure 652. Tornado track of the Hazlehurst January 23, 1969 Tornado. Image 2568.

Figure 653. Path of the F3 Clinton Tornado on the morning of April 15, 2011. Image 2551.

Figure 654. Damage in the Lakeside Subdivision south of Highway 80 in Clinton. At left, a home was ripped from its foundation; the 84-year-old owner of the flipped house was pulled out of the rubble with only a broken nose. At right a home was cut in half by a fallen tree. Pictures were taken April 18, 2011. Image 2552.

ing its winds between a daycare with 150 children and al elementary school with 450 children (**figures 653-654**).

Recovery from disaster. **Figure 655** shows a tornado risk map for the central United States, and the surprising find by Dixon et al. (2011) that Smith County, Mississippi, has the highest tornado risk in the nation. Thus, Mississippi is continuously preparing for and recovering from tornado damage. After the initial search and rescue phase following a tornado touch down, there is the recovery phase of debris removal and restoration of electric power, water, gas, and such. But then there is the problem of where to put all the debris.

Debris removal accounts for approximately 27% of the total cost of a disaster. The Federal Emergency Management Agency (FEMA) defines disaster-generated debris as: "Any material, including trees, branches, personal property, and building material on public or private property that is directly deposited by the disaster. FEMA categorizes natural debris as "vegetative" and man-made debris as "construction and demolition." Some debris requires special handling, while other type can be taken directly to a permitted landfill.

There are three categories of debris removal: (1) Public property debris removal is debris on public property or on right-of-way. It does not require property owner permission for removal and is generally eligible for funding under FEMA's Public Assistance Program. (2) Private property debris removal requires more documentation and approval from a FEMA federal coordinating office must be given prior to the work being done to be eligible for federal assistance. (3) Private property demolition requires a volume of documentation and the involvement of many different stakeholders. When a structure creates an immediate threat to the health and safety of the community at large, private property demolition can be authorized by the FEMA Public Assistance group supervisor (Kevin Cahill, *Disaster Recovery Today*, Issue 13, 2011).

For vegetative debris removal to qualify for reimbursement under FEMA's debris polices and regulations, certain questions must be answered:

1. Will the vegetation be taken to a staging area for reduction?
2. Will the vegetation be recycled? If so, is there any salvage value for the recycled materials?
3. How will debris monitoring be preformed? How will the work be documented?
4. How will limbs that are hanging ("hangers") be treated?
5. How will stumps be treated?
6. Can any of the trees be saved?
7. How many debris-removal runs/passes will be necessary?

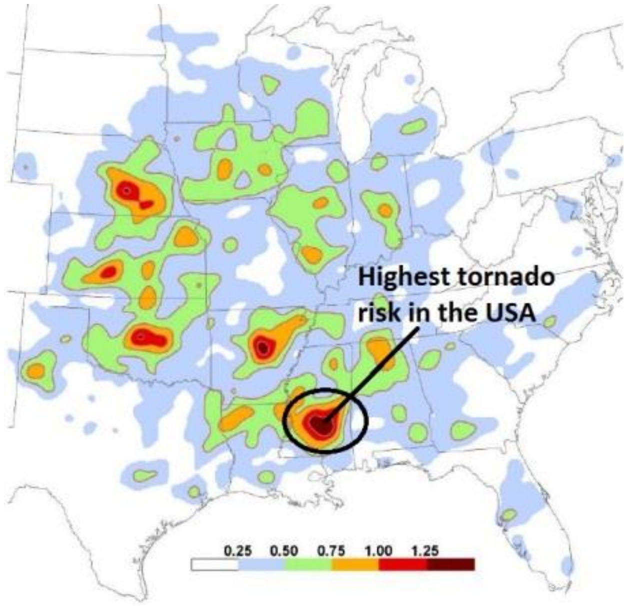


Figure 655. This map is a product of P. Grady Dixon and others (2011, American Meteorological Society) research on the probability of tornadoes in the USA. Their shocking findings indicate that Smith County, Mississippi, has the highest tornado risk in the nation with an average of 1.4 tornadoes or more/year within a 25 mile radius. Image 2553.

The Federal Emergency Management Agency (FEMA) was established under the 1978 Reorganization Plan No. 3, and activated April 1, 1979, by Present Jimmy Carter in his Executive Order 12127. FEMA included disaster relief efforts and absorbed the Federal Insurance Administration, the National Fire Prevention and Control Administration, the National Weather Service Community Preparedness Program, the Federal Preparedness Agency of the General Services, the Federal Disaster Assistance Administration activities from HUD, and Civil Defense from the Department of Defense's Defense Civil Preparedness Agency. FEMA was absorbed by the Department of Homeland Security on March 1, 2003. It became the Federal Emergency Management Agency again on March 31, 2007, but remains in DHS.

FEMA's primary purpose is to coordinate disaster response in the United States that

Figure 656. FEMA regions map. Tha agency has an annual budget of $13 billion that is used and distributed to different states according to the emergencies that occur in each one. Image 2554.

recovery operations such as public assistance.

The Response Office is in charge of coordinating the state's response to any type of natural or man-made emergency through the State Emergency Operations Center.

The Outreach Services Office is comprised of the Individual Assistance Bureau, the Disaster Reservist Bureau, the Disability Integration Advisor and will also include all of MEMA's efforts to work with the different volunteer organizations that we deal with before, during, and after a disaster.

The Support Services Office is in charge of all financial and personnel issues for the agency.

overwhelms the resources of local and state authorities. The governor of the state in which the disaster occurs must declare a state of emergency and formally request form the president that FEMA and the federal government respond to the disaster. A governor's declaration in not required when an emergency or disaster takes place on federal property or assets. **Figure 656** shows FEMA's ten regional contact areas and headquarters.

. **Mississippi Emergency Management Agency (MEMA).** Mission Statement: The mission of the Mississippi Emergency Management Agency is to coordinate activities that will save lives, protect property, and reduce suffering of Mississippi's citizens and their communities impacted by disasters through a comprehensive and integrated program of disaster preparedness, responses, recovery, and mitigation initiatives. The agency is divided into seven offices:

The Mitigation Office helps prevent damage and loss of life and property in future disasters.

The Preparedness Office is in charge of all emergency plans and training programs in the state.

The Radiological Emergency Preparedness Office is in charge of coordinating preparedness efforts related to a nuclear or radiological emergency in Mississippi.

The Recovery Office is in charge of all

Emergency information is released to the public through MEMA with the help of other state agencies involved in the response actions. During any type of evacuation, the Mississippi Public Broadcasting Network will broadcast the evacuation and traffic information on all MPB radio stations.

Gulf Hurricanes. Hurricane Camille was the second strongest U. S. landfalling hurricane in the 20th Century, between the strongest 1935's Labor Day hurricane and 1992's Hurricane Andrew. Camille made landfall in Waveland, Mississippi, on August 18, 1969, with a pressure of 900 mbar, sustained winds of 175 miles per hour, and a peak storm surge of 24 feet (**Figure 657**). The storm flattened nearly everything on the Mississippi coast, killed 143 people on the Gulf Coast, killed 153 people due to flooding in Nelson County, Virginia, and caused $1.42 billion ($9.27 billion 2017 USD) in damages.

Hurricane Camille was predicted to turn eastward toward the Florida Panhandle. In the last 18 hours, it failed the predicted turn and roared ashore near Bay St. Louis as people were sleeping. Biloxi radio stations gave frantic warnings, but those in New Orleans had less dire predictions. Fifty percent of the population stayed to weather the storm.

A persistent story in the aftermath of Camille was of a "hurricane party" held by 23 people on the third floor of the Richelieu Manor Apartments in Pass Christian, Mississippi,

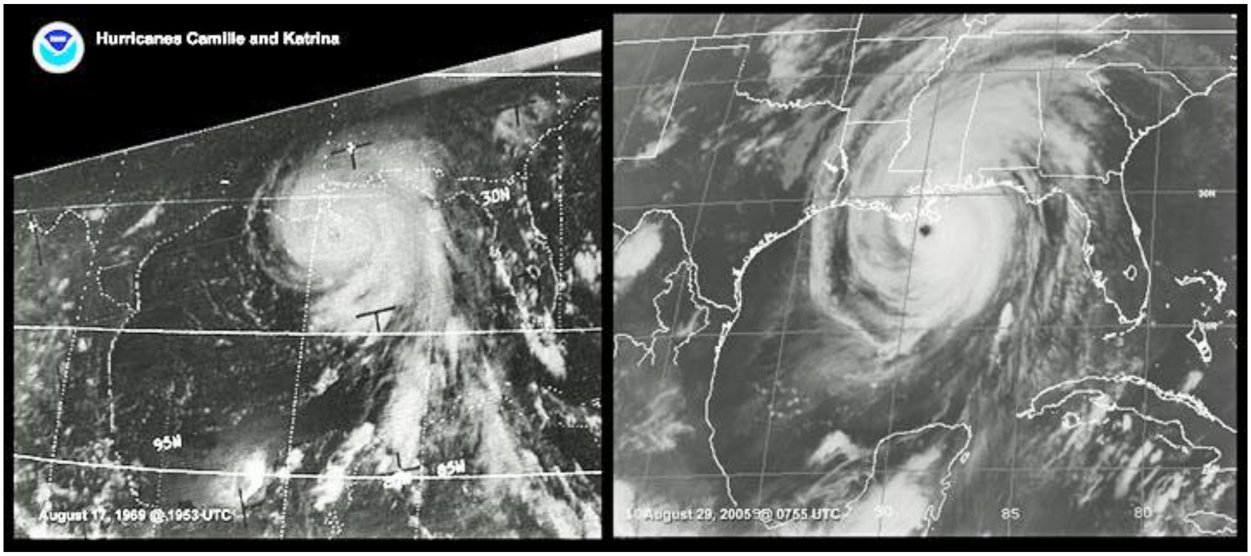


Figure 657. Hurricane Camille (left) on August 17, 1969, as compared to Hurricane Katrina (right) on August 29, 2005. Image 2554.

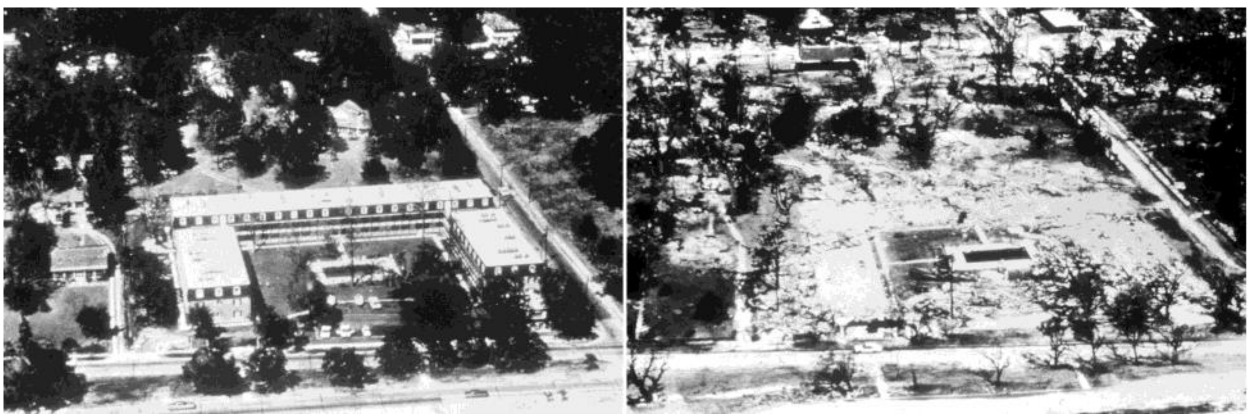


Figure 658. The Richelieu Mannor Apartments in Pass Christian, Mississippi, before (left) and after (right) Hurricane Camille. Twenty three people were staying at the apartments during the storm; eight died. Image 2555.

in which the apartments were destroyed and just one person survived. The amazing true story is that of the 23 people at the apartments, but only eight died in the storm (**Figure 658**). One survivor denied the party story, but Bobbie Morali (personal communication), whose family lived a block away from the hotel and evacuated before the storm made landfall, said that a policeman later told them he stopped by the hotel twice trying to get everyone to evacuate. On the second warning he told them he wouldn't be coming back. The policeman noticed that those who stayed had been drinking.

A lady officer friend of the Morali family stayed behind in her home two blocks from the beach. Her body was eventually found under a pile of mud and tree debris. The Morali family moved from the coast after the storm as their house and father's workplace were destroyed and there was no reason to return.

Hurricane Katrina (as summarized from Margie Kieper's 16 part series posted on Weather Underground). Hurricane Katrina formed as a disturbance in the Atlantic off the east Florida coast on Tuesday August 23, 2005, and was upgraded to a tropical storm the next day. Within the lifespan of exactly one week, it would become the most costly storm in U.S. history. Katrina became a hurricane Wednesday as it headed for the Florida coastline. Instead of crossing the middle of the Florida Peninsula as forecasted, the storm move south and crossed over the moist Everglades entering the Gulf of Mexico intact and further south than expected. The eye of the storm passed directly over the National Hurricane Center in Miami. As the storm entered the Gulf, the forecast was for the hurricane to make landfall along the mid-Florida panhandle. However, Katrina continued to move southwest as a high pressure ridge over the

Figure 659. Day by day track and intensity of Hurricane Katrina from August 23 to August 30, 2005. On August 28 and 29, Katrina was a Mississippi storm. Image 2569.

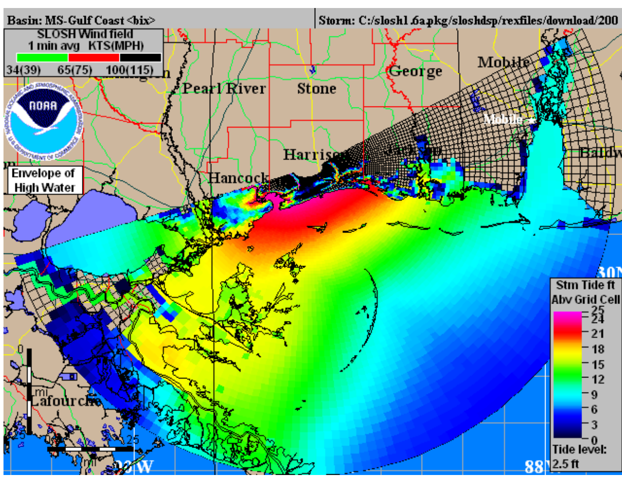
Figure 660. Eye of Hurricane Katrina over Waveland, Mississippi, on August 29, 2005. Image 2570.

Southeastern U.S. did not weaken as predicted. Dramatic new forecasts placed the storm track to target the Alabama-Mississippi coastline and then the Mississippi-Louisiana coastline, placing New Orleans and the vulnerable Mississippi coast at risk of a storm surge.

Other factors that strengthened the storm were a light wind shear over the Gulf and a large upper level anticyclone that covered the entire Gulf of Mexico, stalling the storm while it re-intensified over warm water. Surface waters in the Gulf were one to two degrees above normal and even higher in the shallow waters of the northern Gulf. A warm water Loop Current eddy was south of the Louisiana-Mississippi coastline. Early Friday morning the National Hurricane Center (NHC) issued the notice that, “All indications are that Katrina will be a dangerous hurricane in northeastern Gulf in a couple of days.” Each Friday morning update showed an increase in the storm. By 5:00 p.m, the NHC reported, “Katrina is expected to be moving over the Gulf Loop Current after 36 hours … which … should allow the hurricane to reach category four status before landfall occurs. In just 12 hours from 5:00 a.m to 5:00 p.m. the storm increased from a maximum of 90 knot wind

Figure 661. Picture taken from a second floor window of Bill Bradford's home on Bradford Lane in Waveland, MS., by his wife Judith. The ground level is 18 feet above sea level, and the storm surge is another 10 feet up to the first floor roof. Outside a neighbor is floating by on his roof in a tiny life jacket clutching a neon green pool noodle and holding his dog surrounded by wind-bent trees. The picture was taken after 9:00 a.m. in the calm of the hurricane's eye around maximum storm surge between 9:00 and 10:00 a.m. on August 29, 2005. The Bill swam out to bring this man and two others to safety. Image 2571.

Figure 662. Red circle at left marks the spot of the Bradford's home on the 18-foot contour above sea level in Waveland, Mississippi. Image 2572.



/Figure 663. Height of Hurricane Katrina's storm surge along the north central Gulf of Mexico shoreline. Image 2573.

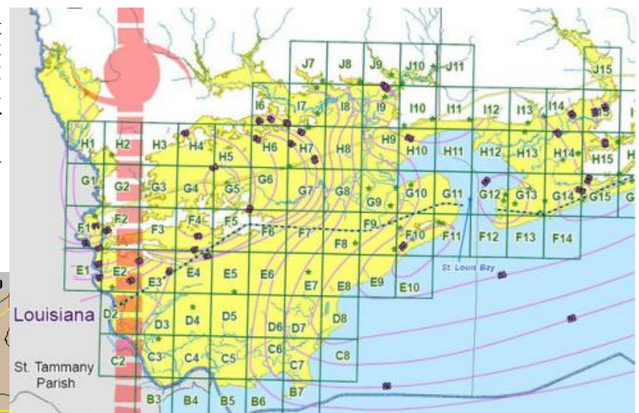


Figure 664. Depth of storm surge inundation at Waveland and Bay St. Louis, Mississippi, between 9:00 and 10:00 a.m., August 29, 2005. Image 2574.

speed to 115 knots, and the storm track had shifted southwest some 170 miles of it predicted path.

A new storm track now placed Hurricane Katrina to make landfall on the Mississippi-Alabama border in 72 hours. The NHC broadcast was, "The models have shifted significantly westward and are now in better agreement. This has resulted in the official forecast track being shifted about 150 NMI west of the previous track." The 11:00 p.m. NHC advisory gave this ominous report and a further westward shift: "The official forecast brings the core of the intense Hurricane (up to 131 knots) over the north central Gulf of Mexico in 48 hours or so. It is worth noting that the guidance spread has decreased and most of the reliable numerical model tracks are now clustered between the eastern coast of Louisiana and the coast of Mississippi. This clustering increases the confidence in the forecast."

A comprehensive Hurricane Evacuation Study (HES) by the U.S. Army Corps of Engineers in December of 2001 created maps that showed the flood surge of a category 4 or 5 hurricane to inundate over 90% of the populated areas of the Mississippi Gulf Coast. The entire Mississippi coast would be encompassed by Katrina's storm surge. Early Saturday morning, the first advisory noted a central pressure drop and intensifying winds from 115 to 120 knots. The mid-morning advisory stated, "It is not out of the question that Katrina could reach category 5 status at some point before landfall." This warning was timed to coincide with the passage of Katrina over warm Loop Current waters. Katrina not only intensified to match the most extreme expecta-

Figure 665. People search for their belongings among debris washed up on the beach in Biloxi on August 30, 2005. CNN Remembering Hurricane Katrina. Image 2575.

Figure 666. Katrina storm surge debris in Pass Christian, Mississippi, August 30, 2005. Image 2576.

tion, but expanded at a tremendous rate. During the weekend Katrina's tropical storm winds expanded eight and a half times their original extent, and the hurricane filled two thirds of the Gulf of Mexico. The size of the storm created a long fetch for the storm surge east of the eye wall.

Many evacuated the coastal areas on Saturday as reports came that the storm was intensifying. Those who stayed awoke on Sunday to find that Katrina had grown to an enormous category 5 storm. The first daylight satellite images of Katrina on Sunday of August 28th showed that the storm had grown into a well organized and powerful hurricane with a large eye and a well-defined outflow pattern. The Sunday forecast advisory began with a simple statement, "Katrina continues to intensify and grow larger." A 7:00 a.m. Sunday special advisory announced Katrina's category five status with a central pressure of 700 MB and flight-level winds of 153 knots. Katrina was expected to be, "a devastating category four or five at landfall." In layman's terms, Katrina was not going to destroy but completely obliterate. The HES maps for Mississippi indicated complete inundation and devastation of the state's entire coastline.

The 11:00 a.m. Sunday forecast rasied the storm's intensity again to 150 knots. The forecast stated, "A drop in the eye gave a central pressure of 907 MB. Katrina is comparable in intensity to Hurricane Camile of 1969...only larger." Through the entire Sunday afternoon Katrina maintained category 5 status and satellite presentation with its remarkably large eye, a close to perfect storm. The late Sunday advisory stated, "Katrina is maintaining a classic presentation of satellite images .. And category 5 intensity. The central pressure measured by a NOAA hurricane hunter plane at 1755Z and 1923Z was 902 MB...which is the fourth lowest on record in the Atlantic Basin behind Hurricane Gilbert of 1988."

Figure 667. The Highway 90 bridge over Bay St. Louis in Pass Christian, Mississippi, is folded and destroyed from Katrina's storm surge, August 30, 2005. Image 2577.

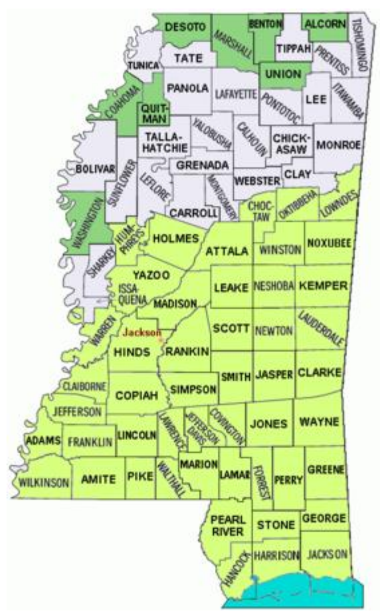
Figure 668. A residential area in Gulfport, Mississippi is inundated with shipping containers, RVs, and boats washed ashore by Hurricane Katrina as seen on August 30, 2005. Image 2578.

Figure 669. The strongest winds of Katrina were in Louisiana and Mississippi on the eastern side of the storm track. Image 2579.

By late Sunday the time to evacuate had run out, and Monday was annihilation. Late Sunday was the peak of a continuous intensification during a two day trip of the Loop Current. As the core moved north of the Current and as part of its oversized circulation moved on land, wind shear increase and dry air was pulled in eroding the western side of the storm. The dry air reached the eye wall reducing the winds on the western side of the storm in both expanse and intensity before landfall.

The hurricane's diminished winds were not the main story of the storm. New Orleans residents on the storm's west side thought the city had "bitten the bullet" again. The main story was the tremendous storm surge that had built up when the storm was a category 5 hurricane. This surge was carried with the storm onto the shallow shelf of the northern Gulf Coast. The size of the surge was due to the vast stretch of water (fetch) subjected to the winds on the eastern side of the large eye wall

Figure 670. All 82 Mississippi counties were declared disaster areas after Katrina. The lower 49 in light green were given full disaster assistance. Dark green areas were given only public assistance Category A/B. Image 2580.



at peak intensity in the open Gulf. On top of the surge were large waves that radiated out from the storm, which were generated at category 5 strength. Buildings along the coast, which had stood for centuries, were taken down by the surge (figures . The surge extended from Plaquemines, St. Bernard, and portions of St. Tammany parishes, Louisiana, the whole Mississippi coast, to the southern portions of Mobile County, Alabama. In Mississippi, the maximum surge was 24 to 28 feet along a swath 20 miles wide centered at Bay St. Louis and was 17 to 22 feet along the eastern Mississippi coast from Gulfport to Pascagoula (**figures 665-668**). The Mississippi surge penetrated six miles inland on many portions of the coast and twelve inland along bays and river.

Hurricane Katrina's strongest winds did much damage in Louisiana and Mississippi as shown in **Figure 669**. MDEQ Office of Geology Katrina responder James Starnes characterized the wind damage this way: "Katrina followed Highway 49 to Hattiesburg and took the Interstate 59 exit to Meridian." All 82 Mississippi counties were declared disaster areas (**Figure 670**). Wind damage cut power to most of southern and central Mississippi. Without power, gas stations could not pump gas, and those that could soon ran out of supply, creating a gasoline shortage that outlasted the power outage. In the midst of disarray in Central Mississippi, MDEQ sent a response team to the Gulf Coast to assist with debris removal. On September 3, 2005, MDEQ Executive Director Charles Chisolm issued a "Hurricane Katrina Disaster Debris Management Response, Vegetative Debris Disposal" for the hardest hit southern and southeastern counties to facilitate the management, burning, chipping or other volume reduction efforts of vegetative debris. On September 4, MDEQ granted emergency authorization to the same counties for "Building and Structural Debris Disposal." On September 27 a MDEQ policy statement for "Hurricane Katrina Disaster Debris Management Response, Automobile, White Goods, and Other Metal Recycling/ Disposal" was issued. White goods include major home appliances such as washers, dryers, refrigerators, freezers, hot water heaters, and other larger comparable appliances. Many of these items ended up on the beach, carried there by the retreat of the storm surge. Spoiled food in refrigerators and freezers were required to be placed in suitable waste containers.

MDEQ early response to Hurricane Katrina is outlined in **figures 671-672**. Pre-deployment plans began on August 24 when Katrina was upgraded to a tropical storm off the east coast of Florida. When the Katrina entered the Gulf of Mexico on August 26, MDEQ's State Emergency Response Team (SERT) was activated and preplanning for the possible emergency began. On August 26 as the hurricane move southwestward through the Gulf, MDEQ staffed the Mississippi Emergency Operation Center (MS EOC). On August 28 as Katrina strengthened, MDEQ sent a forward team to Camp Shelby with Mississippi Emergency Management Agency (MEMA), and the U.S. Environmental Protection Agency (EPA) staffed MS EOC. As the hurricane made landfall on August 29, MDEQ, SERT, and contractor finalized the plan for mobilization. On August 30, after heavy winds and storm surge, MDEQ's full SERT team was deployed to the coast; at this time six EPA teams were deployed to Mississippi and Alabama. On August 31, as Katrina moved into

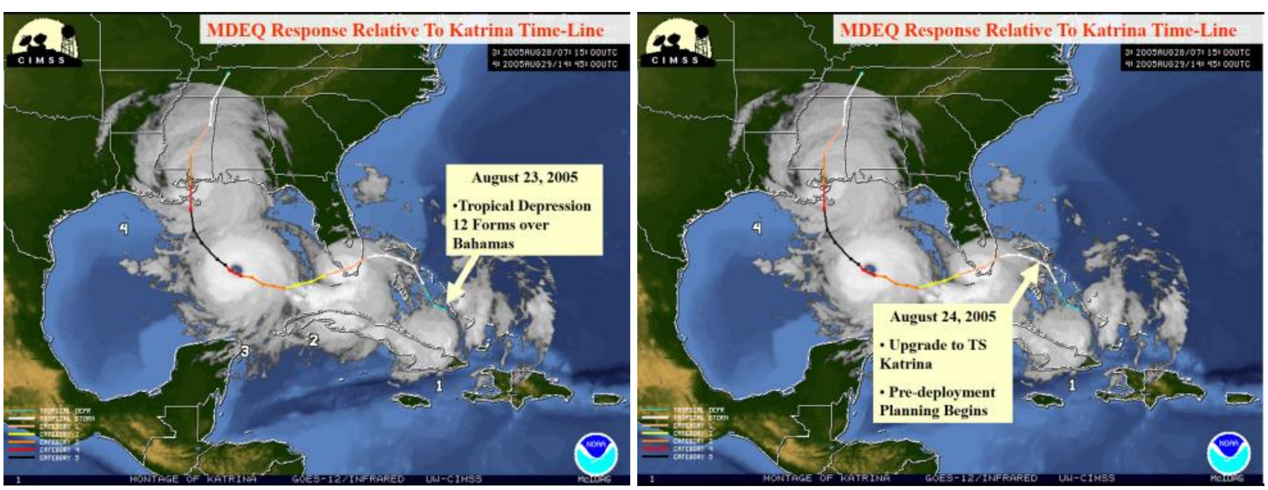


Figure 671. MDEQ response relative to Katrina time-line, a 2008 PowerPoint presentation by Richard Harrell for August 23-24, 2005. Images 2581-2582.

Tennessee, four MDEQ teams begin assessments along coastal Mississippi, and six EPA teams begin assessments along coastal Mississippi and Alabama.

The first wave of MDEQ responders lived out of their vehicles with no power or running water (**figures 673-677**). James Starnes, Office of Geology, arrived in a second wave of volunteers in September and stayed in a USDA poultry inspection lab in Gulfport that had survived the storm. The site was chosen because it was protected by a razor wire fence and a secure location for personnel, equipment,

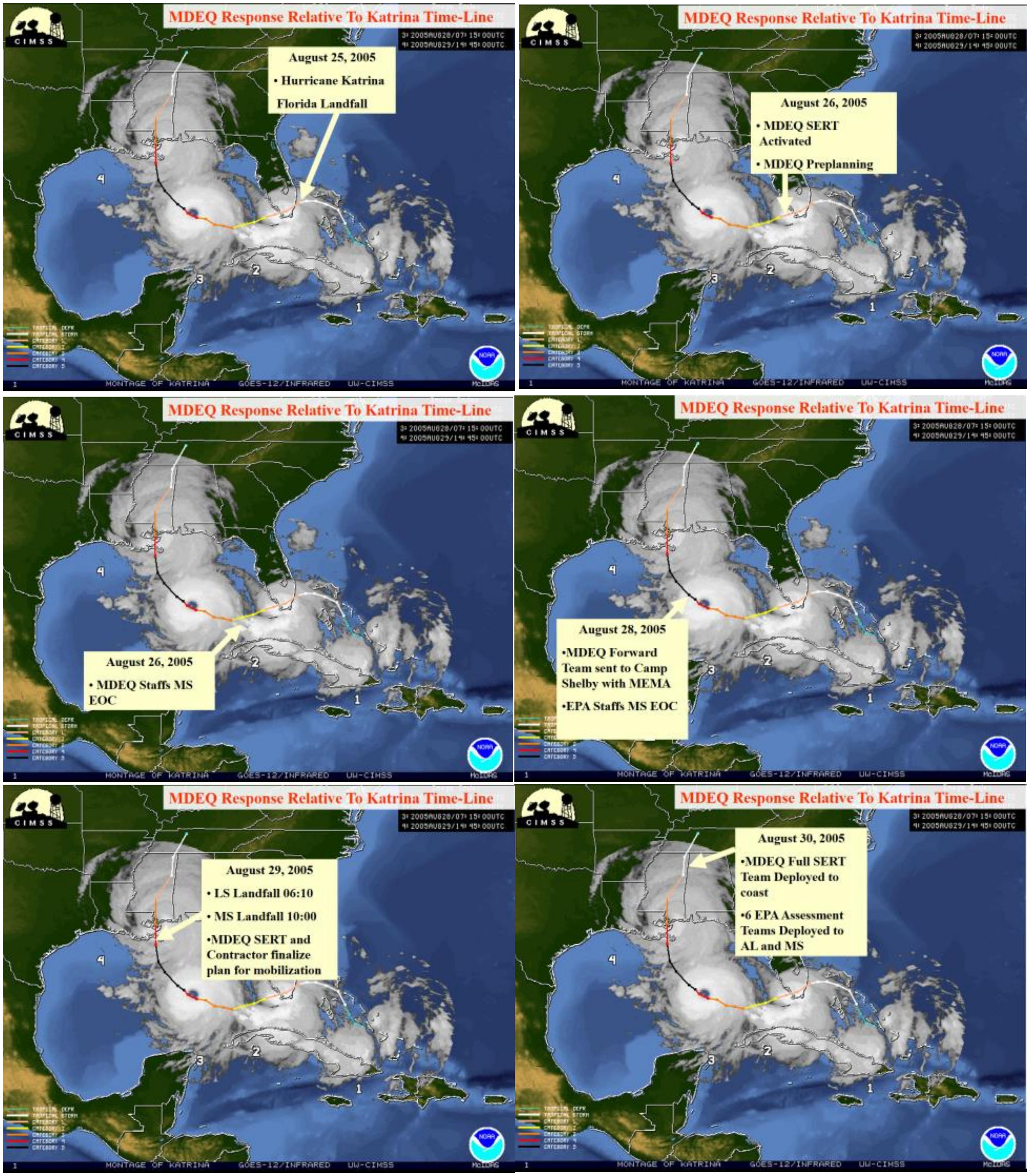


Figure 672. MDEQ response relative to Katrina time-line, a 2008 PowerPoint presentation by Richard Harrell for August 25-30, 2005. Images 2583-2586.

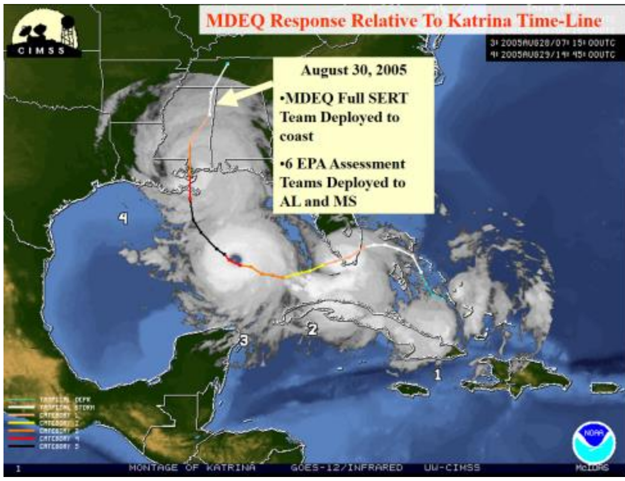


Figure 673. MDEQ response August 31. Image 2587.

Figure 674. A search and rescue worker filling his vehicle directly from a fuel tanker truck, the only source of gasoline on the coast. Picture from Richard Harrell. Image 2588.

Figure 675. Oakland Fire Department's California Task Force 4 (CATF-4) Urban Search and Rescue team with their cadaver dog. One of 28 Urban Search and Rescue (USAR) teams funded nationwide by the Federal Emergency Management Agency (FEMA). Picture from Richard Harrell. Image 2589.

Figure 676. House marked after being searched by a search and rescue team on August 30, 2005. Picture from Richard Harrell. Image 2590.

Figure 677. Initial MDEQ response met concerns of "Human Health and Safety" such a scavenged food goods from stores by hungry storm victims. Image 2591.

and food. At the time, storm victims were looting for food and other necessities. Staff work up to 20 hour days, with some meeting lasting most of the night, and were fed at the county emergency operation centers. There was marshal law with a curfew at dark, but MDEQ vehicles were allowed on the road after dark

Starnes' first project was the Waveland Save-A-Lot, a large grocery store that was unsecured and repeatedly looted. The store parking lot was a Mississippi National Guard and Red Cross food, water, and medical distribution center. The store had six inches of mud on the floor and turned over shelves like dominoes. Perishable food was rotted and covered in maggots; maggots were spread out across the parking lot like ants, invading the Guard

Figure 678. A large mound of debris and a debris staging area. Pictures from Richard Harrell. Image 2592.

and Red Cross distribution centers. The store owner, who owned multiple stores in the same condition, was contacted and connected to a contractor. The distribution centers were moved, and within 24 hours a contractor brought in a vermiculite lined roll off box carried by an 18 wheeler, to load the stores contents for disposal.

Early in Starnes' work, a debris staging area was closed when a body part was found. At the time bodies were still being recovered, and no one knew if the putrid smell in the debris was soiled food, dead animals, or people. A fish packing plant in Pascagoula in summer heat was creating a stench for miles around. The spoiled fish were packaged, preventing a disposal at sea, and were in cinder block freezers. Each freezer was forced air burned to incinerate the spoiled fish and relieve the environmental and public health hazard. The contents of an overturned train load of chickens near Gulfport was disposed at sea.

Figure 679. Hurricane Katrina debris fire. Image 2593.

Starnes was also involved in finding new staging areas environmentally appropriate for household goods in Hancock County. Wetland areas were excluded from this use, and only high and dry ground was acceptable for this Class II material. Every sandpit in the coastal area was used for the permanent disposal of Class I (reduced vegetative debris; **figures 678-679**) and Class II material. Hazardous materials were shipped to appropriate disposal facilities (**Figure 680**).

MDEQ'S STATE EMERGENCY RESPONSE TEAM

The following is from *Environmental News*, volume 7, issue 4, May 2010, page 26. As part of MDEQ's mission and cooperation agreements with other agencies and departments, there is a need for staff to respond to large-scale natural disasters and emergency events involving chemical, biological and radiological materials. Under the state's Comprehensive Emergency Management Plan, MDEQ is tasked as the lead agency for Hazardous Materials Response.

While MDEQ has a permanent Emergency Services Division (ES), they have limited staff and resources to draw upon in emergencies so when needed they utilize other MDEQ staff and their expertise. Eric Dear, current Chief of the Emergency Services Division, established a more formal system that could easily be implemented and trained to federal requirements. The plan included planning to meet the staffing demands of large scale events, Emergency Operations Center activations, and MDEQ's role in the state's Comprehensive Emergency Management Plan developed by MEMA. As part of the reorganization, a formal MDEQ State Emergency Re-

Figure 680. Hazardous materials abandoned at facility past shelf life and unstable and explosive. Drums had to be opened and stabilizer added to prevent uncontrolled polymeric reaction before they could be shipped for disposal. Image 2594.

sponse Team (SERT) was established, outfitted, and trained. This group consists of engineers, geologists, and scientists within the agency that can be called up to aid ES staff during large environmental events. The MDEQ State Emergency Response Team has completed special training in: hazardous materials sampling; Personal Protective Equipment (PPE), safety and respirators; National Incident Management Systems; Air Monitoring; Response to Weapons of Mass Destruction; Train derailments; among other things.

SERT members have assisted in the responses to: the failure of Big Bay Dam; Hurricanes George, Katrina, Rita, and Gustav; train derailments; air monitoring for Presidential security; an anthrax scare in 2001; and outreach activities. The SERT team continues to participate throughout the year in MEMA disaster exercises related to hurricanes and the Grand Gulf Nuclear Plant as well as serving on the state's Hazard Mitigation Planning Committee and the state's Pandemic Response Plan development.

Emergency Response for British Petroleum's Deepwater Horizon/Macondo Blowout Well.

The BP Deepwater Horizon well blew out catastrophically on April 20, 2010, killing 11 crew members. Efforts to extinguish the flames were unsuccessful, and the rig sank on April 22. Oil gushing from the broken pipe just above the seafloor poured forth an estimated 62,000 barrels per day into the Gulf of Mexico off the mouth of the Mississippi River. The flow continued until the well was finally capped on July 15, 2010. It was the largest marine oil spill in the history of the petroleum industry. The well was declared sealed on September 19, 2010.

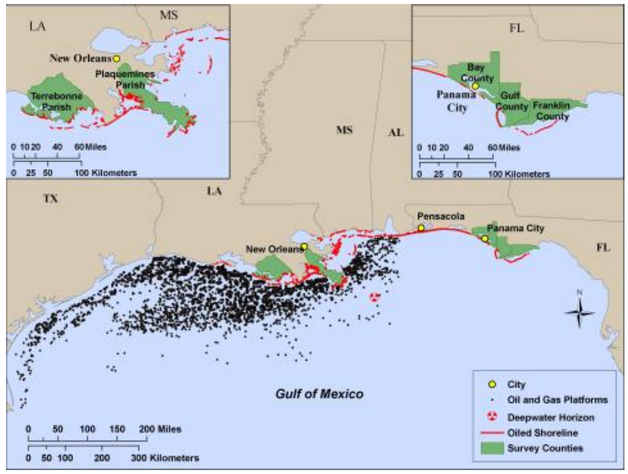


Figure 6817. A map of Gulf of Mexico oil and gas platforms, the site of the Deepwater Horizon blow out, the oiled shoreline resulting from the oil spill, and five counties surveyed by University of New Hampshire researchers. Map credited to Lawrence Hamilton. Image 2595.

A massive response was mounted to protect beaches and wetlands and estuaries from the spreading oil with the deployment of skimmer ships, floating booms, controlled burns, and 1.84 million gallons of the oil dispersant Corexit. Some 4,900,000 pounds of oily material were removed from Louisiana beaches in 2013, and oil was found on beaches are far away as Tampa Bay, Florida.

MDEQ staff debriefing on emergency response to the BP oil spill. MDEQ and DMR working to protect Mississippi coastal resources

The following is from *Environmental News*, volume 7, issue 6, August 2010, pages 1-8. The Mississippi Department of Environmental Quality (MDEQ) and the Mississippi Department of Marine Resources (DMR) continue to lead the

Figure 682. Earl Etheridge (rt) with Governor and Mrs. Haley Barbour at Henderson Point examining skimmers. Image 2596.

Figure 683. Earl with Congressman Gene Taylor and the crew of a National Guard UH-72. Image 2597.

state response to protect and restore the vital natural resources of Mississippi's Gulf Coast from the Deepwater Horizon incident.

This month's newsletter features interviews with four people who have been heavily involved in the state's response and have diligently worked long hours to ensure that Mississippi's interests were protected.

Earl Etheridge (Emergency Response)

Earl Etheridge is MDEQ's Emergency Response coordinator on the Gulf Coast working out of the agency's regional office in Biloxi. Prior to that he served 26 years with the Moss Point Fire Department including three years as Fire Chief.

1. What has your role been for MDEQ during the oil spill response? How did that change as the response progressed?

I work in the emergency response division. When the incident first started, I worked closely with the local counties and cities on what was going on and our unfolding response. During the first weeks of May I stepped over to working more closely with the Department of Marine Resources, the Mississippi National Guard, the Coast Guard, and BP, as well as the counties. I started handling flight operations for the agency with the National Guard and this led to my call sign as "Big E." With the addition of the leased skimmers and the building of the state's skimmers this was also added to my job duties. After the Mississippi Command was stood up, I still did all of the above but also stood in as the MDEQ representative for this unified state command. It was good fortune to have great people from not only our agency but also the other state agencies and the Coast Guard. We could not have done our job without them. They made our response possible.

2. What do you think is the unknown story or information about the oil spill that the public may not know?

The biggest unknown story I think is the response MDEQ staff did with the State Emergency Response Teams and the Shoreline Cleanup Assessment Teams. The hours spent walking the beaches, listening to local citizens and officials, and their dedication to the response was what made things work.

3. What has been the biggest challenges MDEQ faced? What about for you?

The biggest challenges MDEQ faced, from my view, was the misinformation that circulated throughout the three counties as well as rumors. By going out to county emergency management meetings, the town meetings, and showing the flag every day our people were able to counter this. For me it was the around the clock phone calls, the being gone from home every day from the end of April to the first of August. My wife was great in dealing with this.

4. Are there things in hindsight you would have done differently?

Try to engage the local officials more. It was easy to get wrapped up in the response and not reach out like I should have to them.

5. In your view, what are some of the important tasks for MDEQ, the state, and for you in the future?

The agency needs to be build on this response and take the things that work and add it in to our training and plans. Never forget we work

Figure 684. Richard Harrell on patrol with the National Guard. Image 2598.

Figure 685. Unified Command in Mobile. Image 2599.

Figure 686. Richard with Alabama and Florida representatives at Unified Command. Image 2600.

for the people of this state and not just some organization. For me, I have learned a lot about working a long varied response. I think I can take what I learned and serve the people better.

6. In what ways has this response stretched your abilities and knowledge?

I learned that no one can do this alone. It is a team effort not only within our agency but it takes all the state agencies to work together on a response like this. After Hurricane Katrina my area of response was limited to looking for drums and tanks. In this I did more of overall local operations on a coastwide scale. I had to learn to fit the need.

Richard Harrell (Environmental Permits Division)

Richard Harrell has served primarily as the State-On-Scene Coordinator at Unified Command in Mobile, among a myriad of other duties, and has been in oil spill response mode since the leak started.

1. What has your role been for MDEQ during the oil spill response? How did that change as the response progressed?

For an oil spill the governing law is the Oil Pollution Act (OPA). It required an Area Contingency Plan (ACP), planning, pre-identification of sensitive areas, and established sectors. Mississippi was part of Sector Mobile which covers all of Mississippi, Alabama, and the Panhandle of Florida. Additionally the director of MDEQ, Trudy Fisher, is the appointed Natural Resources Trustee for Mississippi by the Governor. Our agency has worked many inland oil spills under OPA in this role, but never one of this magnitude.

Many of the plans for sampling, debris management, boom placement, cleanup techniques were under development and had to be approved by Unified Command for Sector Mobile. Since May 2010, numerous staff with MDEQ have been reassigned to work oil spill activities from tissue sampling, sediment sampling, water sampling, beach monitoring, working with the county governments, regulatory oversight of BP contractors, and roles within Unified Command-Sector Mobile. I worked as the State-On-Scene Coordinator at Unified Command in Mobile. Unified Command-Sector Mobile is made up of one Incident Commander from each of the three states (MS, AL and FL), U.S. Coast Guard, the Department of the Interior, and the Responsible Party, BP in this case. As the Mississippi Incident Commander in Mobile, I was responsible for signing off on any plans or activities related to the oil spill response. Like many of MDEQ's dedicated staff, we have typically worked fourteen to sixteen hours a day, seven days a week. Most of our staff worked two to three weeks on oil spill response and then one week in Jackson to keep up with the most crucial parts of our normal job duties. This equates to over 100 hour weeks with only a few days off per month. The engineers, scientists, geologists, and everyone at MDEQ have really stepped up to protect our state's natural resources and citizens in this challenging event. If there is an untold good story behind this event it is that of our citizens and state and local government employees rising to yet another challenge within our state and having a "can do" attitude just like after Hurricane Katrina. It's one of those times that I am proud to be an engineer, state employee, and citizen of Mississippi.

2. What has been your engagement with Unified Command, DMR, the Governor's Office, local officials, BP, and other agencies?

MDEQ and I have had to work closely with the Governor's Office and all those listed above plus many more. Our state's ability at all levels of government to work through issues and maintain a working relationship with BP helped the state to leverage many of our requests effectively. Although there has been criticism of Unified Command and the OPA process, it provided much needed organization to an event this large. In an event of this magnitude involving so many different groups, it has been a challenge coordinating input from all affected parties within the state and managing those requests through Unified Command and the Incident Command System. Like many, MDEQ has been involved in NIMS and ICS training. However, when implemented at this level, I'm not sure any amount of training prepares you for an event like this.

3. What do you think is the unknown story or information about the oil spill that the public may not know?

How many people, agencies, organizations, and contractors were suddenly thrust together and considering all the factors how well most of the processes worked. If you look at the numbers it was like establishing a corporation of 20,000 to 30,000 people in one month with payroll, training, planning, logistics, safety considerations, and all the things that require managing that many people. It's really a pretty amazing feat. Mississippi was able to maintain its role in Unified Command and also incorporate the Mississippi National Guard, the Department of Marine Resources, the State Department of Health, the Mississippi Department of Wildlife, Fisheries, and Parks, the Mississippi Emergency Management Agency, local governments, and others to ensure its interest and priorities were met.

4. What have been the biggest challenges MDEQ faced? What about for you?

Managing expectations, getting accurate information out to all interested parties, and responding to the public's concerns and the uncertainty at the beginning of what the impacts would be to Mississippi and its coastal ecosystem.

Personally, like many involved in this effort, my normal job duties and family requirements remained even though I was spending weeks in a row on the Coast. Trying to manage the thousands of calls, emails, and demands were the biggest personal challenges and still get back to Jackson every once in a while to also manage my normal job duties. When it was time to rotate out you almost hated to leave because things were moving so fast you knew when you got back in a few days it was a huge challenge to catch back up.

5. Are there things in hindsight you would have done differently?

Found a way to improve communication with the public and local elected officials. There was so much misinformation and lack of knowledge early on about what was going on, and this caused much unneeded strife and tension. MEMA and the local county EOC's proved valuable in many ways once we were able to get plugged in and able to share information.

6. In your view, what are some of the important tasks for MDEQ, the state, and for you in the future?

I have observed firsthand the impacts in Mississippi's waters, its marshes, and beaches. MDEQ has worked closely with the Mississippi Department of Marine Resources and the Mississippi National Guard to investigate and assess all impacts to our state. While there is damage to our coastal ecosystem, our beaches are open, most of our fishing in state waters is open, and

Figure 687. Captain Ron and Wesley Floyd in the MDEQ Ready Room. Image 2601.

the Mississippi Gulf Coast is open. I encourage our citizens and those outside of our state to visit the Coast for its many opportunities, ecological treasures, and activities. Much of our shoreline oil spill impacts have been "tar balls" on our beaches and coastlines. These tar ball events are visibly cleaned daily. We expect many years of restoration, but that doesn't mean things are unsafe for our citizens. Currently MDEQ is working with Dr. Bounds and the IHL system to identify experts in numerous fields to help our agency investigate, remediate, and restore our Gulf Coast completely.

7. In what ways has this response stretched your abilities and knowledge?

The duties primarily challenged my organizational skills and stamina. Stamina in working seven days a week, sixteen hour days, was a big challenge to stay focused and keep everyone level-headed. Organizationally there were so many things going on you had to prioritize on the fly to get the major things done first while still keeping up with everything.

The biggest challenge knowledge wise was dealing with the Oil Pollution Act which isn't a regulatory function I deal with every day. Having to learn OPA, the funding process, Area Contingency Plan, and all the caveats associated was a big challenge. There isn't much case history for oil spills in the Gulf, oil spills with this type of crude oil, and definitely not much pertaining to oil spills of this magnitude. There was a huge array of questions about the impacts, fate of the oil as it weathered, and modeling of the trajectories to predict impacts that required a tremendous effort by the scientific community to address.

CPT Ronald A. Rogers Medical Operations 47th CST (WMD) MSARNG

Captain Ronald A. Rogers served as a liaison with MDEQ during the oil spill response.

The staff would like to thank "Captain Ron" for his invaluable assistance and "can do" attitude. The effectiveness of our response would have been limited without his attention to detail and willingness to help.

1. What has your role been during the oil spill response? What is your normal role?

I have been in or around the military for the past 26 years. I am currently serving the state as the Medical Operations Officer for the 47th Civil Support Team with a primary mission of providing assistance to civil authorities in response to suspected terrorist related events. However, following our response to Katrina a Congressional change added any natural or manmade disaster where civil authorities requested assistance to our mission set. Hence, I received a phone call from my Commander on the 3rd of May. As I remember the conversation was "CPT Rogers, I need you to go to Biloxi and speak with Trudy Fisher or Richard Harrell with DEQ and see if there is anything that the Mississippi Military can do to provide assistance in the Deep Water Horizon Response. As always, I said, "Roger that, sir." Later that night I told Mary, my wife, and the boys that I had to go to the Coast for a few days. With that being said, for the past 100 plus days I have continued to be a liaison officer with DMR/DEQ operations.

2. In what ways did you have to interact with MDEQ and with the MDEQ staff?

During this response I had the pleasure of coordinating military assets in support of MDEQ/DMR operations. I feel as though the MSNG played several roles of importance throughout the response. The two key pieces were the information collection effort with aviation assets and utilizing state assessments to form a common communications plan fusing air, water, and ground response resources. This facilitated the joint operations team of MDEQ, DMR, USCG, MSNG, and contractors in the processing of information and imagery in a timely manner. This allowed MDEQ and DMR personnel to execute a well-informed and coordinated response along the Coast using the critical skills brought to the table by their organization throughout the response. Other aspects of support came in the form assisting in the development of a State Oil Response Plan, daily operational planning, and providing situation updates.

3. What are your impressions of the MDEQ staff? Did you learn things about the agency and its responsibilities that you didn't know before the response began?

My interaction with MDEQ staff and members changed as the response evolved. My first interactions were as simple as establishing relationships with staff members that would facilitate a trusted environment. From there it grew into a relationship where daily interactions ranged from flight scheduling, sample protocols and analysis, creating common operations pictures, air quality checks, staging area operations, available response assets, and daily skimming/ Vessels of Opportunity operations. I can say that what was most meaningful was interacting with the diverse groups of MDEQ employees rotating in and out as the weeks progressed. There were obviously stand out moments, however, I cannot think of one bad experience. Each and every member whether working SERT, SCAT, SRO, or Ready Room management were clearly on the Coast in an effort to solve problems as Mississippi faced this event. The countless long hours and dedicated effort produced continuity of information to and from the county EOC's thru ICP Mobile and ICC Biloxi. This greatly enhanced the state's overall response efforts. I think for all of us the learning curve was enormous. To use someone else's words: "for most of us, the next oil spill will be our second." The skill sets brought to the table by MDEQ were diverse and invaluable.

This is not an event I care to relive. But what became clear to me was that Mississippi is blessed to have great people doing whatever it takes to meet the needs of this great state. During this event there were no enemies, just a common problem. I cannot think of any group that I could have worked with to help solve that problem than the staff from MDEQ. There is no doubt that MDEQ has placed incredibly knowledgeable and capable individuals in the right positions. I feel certain that I will exploit relationships that I have developed over the past few months to enhance my ability to respond to other events that may face this state in the future. Don't be surprised if you see my number on the caller ID in the future. I would like to say to Ms. Fisher: "Thank you for the opportunity to work

Figure 688. Barbara Viskup on patrol with the Mississippi National. Guard. Image 2602.

with your staff. What a dynamic team and capable team. I am a better person and soldier because of this opportunity." To the rest of you: "God Bless, and thanks for being who you are and doing what you do."

Barbara Viskup has been with MDEQ for 14 years as a biologist at the South Regional Office in Biloxi. She graduated from the University of Southern Mississippi and has a masters from USM in biology with an emphasis in aquatic ecology.

1. What have been your duties since the oil spill began? Why were you designated to help direct the placement of boom?

When I first went to the Unified Command Center in Mobile in April, I was designated as an Environmental Specialist in the Planning Section. Aside from having to oversee boom placement, I also had to help designate sensitive areas across our coast. Some of these sensitive areas are where threatened and endangered species reside, birds are known to nest (least tern areas), oyster reefs, and other areas of archeological/historical importance such as shell middens. Some of my other duties consisted of overseeing the Shoreline Cleanup Assessment Team (SCAT) program for Mississippi, the placement of decon sites for cleaning boats, helping the DMR representative with the Vessel of Opportunity program, reading and commenting on many of the plans coming out of the planning section, and acting as a liaison for the state.

2. What has been your reaction to the oil spill duties? What has stretched your abilities and knowledge?

The duties associated with my job have been overwhelming and very stressful at times. I have never worked on a spill this large and constantly stayed within an environmental response mode. I have impressed myself with my knowledge of the Mississippi coast and how in an instant I can find myself answering many unrelated questions quickly and accurately without batting an eye. You never realize how well you know an area until you are required to do everything you can think of to help defend this area from any damage that could occur.

3. How do you believe MDEQ staff has made a difference in oil spill response and for the long -term health of the Coast, the Barrier Islands, and the Gulf?

I believe we have followed our mission statement in protecting the state's air, land, and water to the best of our ability. Personnel have made themselves visible prior to and after the oil came into the state's waters by sampling the water, the biota, and continuing to do air monitoring. It is important that residents across the Coast notice this and for the most part are reassured that we are doing what we can to keep the coast safe. Having done a lot of sampling prior to the spill gave us needed baseline data for waters, sediment, air, and seafood. Having responsibility for overseeing most of the cleanup that has already taken place will help with the recovery of our Coast.

MDEQ BEGINS INTENSIVE MONITORING FOR SUBMERSED OIL IN THE SOUND (August 2010)

The following is from *Environmental News*, volume 7, issue 6, August 2010, page 9. The Mississippi Department of Environmental Quality (MDEQ), in coordination with the Unified Incident Command in Mobile, announced on August 17, that it is launching an initiative to systematically sample for submersed oil in the Mississippi Sound. This intensive effort will extend from Mobile Bay to the Louisiana state line, and the initial phase is expected to be completed in approximately fourteen days with weather permitting. "Fish and shrimp in Mississippi waters are safe to eat based on the extensive water and seafood sampling conducted by multiple federal and state agencies. We are implementing this monitoring effort to provide a more complete picture of whether any oil remains in our waters and to address the questions we all have about potential underwater oil. A three-pronged sampling effort should provide a good picture of what is or is not in the Mississippi Sound. If there is oil in water column, we want to know about it and deal with it. If it is not, then we want to put an end to the underwater oil assertions which is only damaging the marketability of our seafood, " said Trudy Fisher, MDEQ Executive Director.

This plan, employing Vessels of Opportunity and six of the state-owned skimmers, includes three separate and unique tactics to investigate the existence of submerged oil in the Mississippi Sound:

•Sorbent Probes Deployment and Water Sampling The first method uses about 30 private vessels from the Vessels of Opportunity Program using sorbent probes and depth finders to find and delineate areas of suspected oil below the water's surface. The Mississippi Sound will be divided into a grid, made up of areas that are approximately 2 miles on each side, an area of approximately four square miles. This grid formation will create approximately 180 distinct areas of approximately equal size that will be thoroughly surveyed for the presence of submerged oil.

The six sampling boats, staffed by MDEQ, will collect samples from any areas of suspected oil identified by the surveying vessels.

The surveying vessel will deploy sorbent probes at regular intervals along the survey route, and also when depth finder readings indicate something suspicious below the surface. If the probe indicates that potential submerged oil is present, the survey team will contact the MDEQ sampling team to initiate sample collection activities. Samples will be analyzed for petroleum compounds, dispersants, and phytoplankton or algae.

•Fluorometer Readings and Water Sampling The second sampling technique will involve the continuous measurement of oil in the water column as a vessel will tow a submersible fluorometer along a specified course from Mobile Bay to the mouth of the Pearl River on the western side of Hancock County. This instrument will continuously monitor for oil plumes, and this real time data will be coupled with GPS locational data and other routine water quality data including oxygen, temperature and salinity. Sampling technicians aboard the vessel will collect additional samples when the flourometer detects the presence of oil in the water column. This technique has been used successfully in deepwater studies aboard oceanographic research vessels, but this will be the first time this has been used in Mississippi Sound.

•Sediment Grabs The third part of this sampling effort will focus on oil in or on the bottom sediments of the Sound. A separate vessel and crew will be dedicated to this task. The crew will collect sediment samples along a specified course throughout the Sound. The samples will be inspected visually and by smell for the presence of oil, and if oil material is suspected, samples will be collected for further analysis.

Central United States Earthquake Consortium (CUSEC), Emergency Response to Earthquakes

CUSEC was established in 1983 with funding from the Federal Emergency Management Agency. The Consortium is a partnership of the federal government and the eight states most affected by earthquakes associated with the New Madrid Seismic Zone in the central United States (**Figure 689**), which are Alabama, Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee. The organization's primary mission is, "the reduction of deaths, injuries, property damage and economic losses resulting from earthquakes in the Central United States." According to its website, "CUSEC serves as a 'coordination hub' for the region, performing the critical role of coordinating the multi-state efforts of the central region. Its coordinating role is largely facilitative and not as the primary implementer of emergency management functions, which is the responsibility of each individual state." Outreach goals of the organization include, multi-state planning, public awareness and education, mitigation, and research.

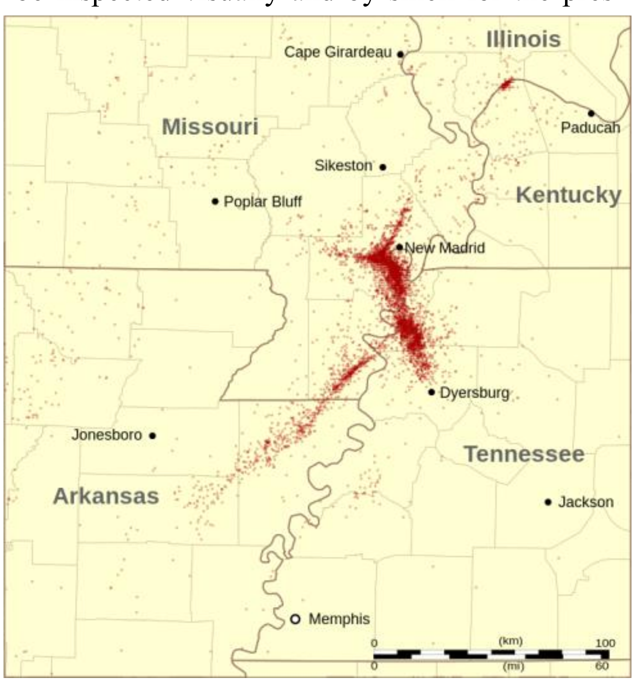
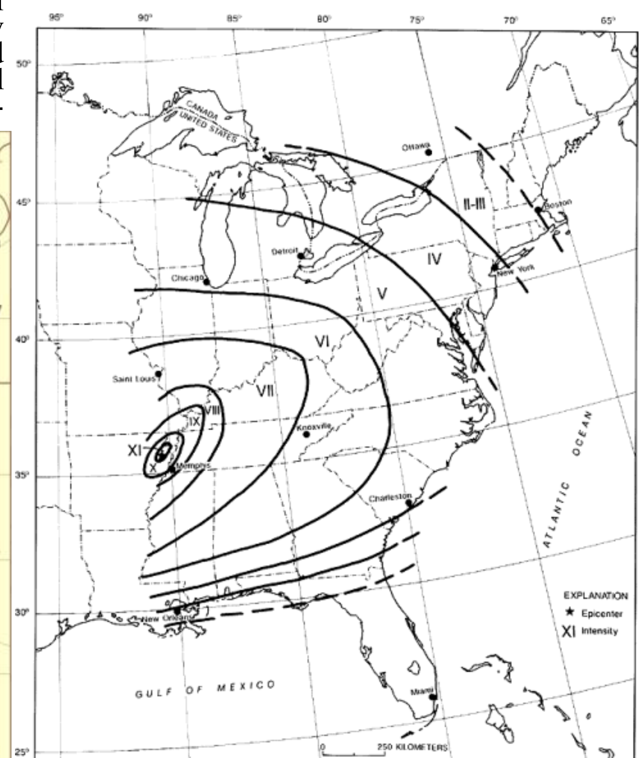


Figure 689. The New Madrid Seismic Zone is outlined here by the epicenters of more than 4,000 earthquakes recorded since 1974. From Wikipedia. Image 2603.



IFigure 690. Isoseismal map of a the December 16, 2811, earthquake in northeastern Arkansas near Memphis, Tennessee as measure on the Modified Mercalli scale (from Stover and Coffman, 1993). Image 2604.

The earthquake damage risk for the CUSEC states is evaluated on the basis of several large earthquakes that occurred in December of 1811 and January of 1812.

December 16, 1811, at 2:15 a.m. a magnitude (M) 7.2—8.2 earthquake with an epicenter in northeastern Arkansas caused slight damage due to the sparsely populated area. However, the future location of Memphis, Tennessee, was shaken at Mercalli level nine intensity. The event rang bells in Richmond, Virginia, and knocked plaster off walls in Columbia, South Carolina. Some 27 aftershocks followed at six to ten minute interval until the Daylight Shock.

December 16, 1811, at 8:15 a.m. a M 7.2 –8.2 earthquake with an epicenter in northeastern Arkansas, followed the first earthquake by about six hour and was judged to be of the same strength. (**Figure 690**)

January 23, 1812, at 9:00 a.m. a M 7.0 –8.0 earthquake centered in the Missouri Bootheel caused ground warping, ejections, fissuring, severe landslides, and caving of stream banks.

February 7, 1812, at 4:45 a.m. a M 7.4 –8.6 earthquake with an epicenter near New Madrid, Missouri, destroyed the town of New Madrid and severely damaged many houses in St. Louis, toppling chimneys. The earthquake was on a reverse fault segment of the Reelfoot Fault that crossed under the Mississippi River just south of Kentucky Bend. The uplift of the river bed created temporary waterfalls on the Mississippi and sent a wave of water upstream. The earthquake also created Tipton Dome and Realfoot Lake. The earthquake was felt in New York City and Boston, where ground motion caused church bells to ring. Hundreds of aftershocks followed until 1817.

Jay Feldman's account of the 1811-1812 New Madrid earthquakes entitled *When the Mississippi Ran Backward* (2005, Free Press, 307 pages) weaves the impact of these earthquakes on the region's history and people. His narrative includes the legendary prophecy of Shawnee Chief Tecumseh who was trying to forge an Indian alliance to defeat the European settlers. He believed his mission to be divinely given but found Big Warrior, a mixed blood Creek chief, to be uncooperative. "Your blood is white," he told Big Warrior, who doubted his mission. "You shall know. I leave Tuckhabatchee directly and shall go straight to Detroit. When I arrive there, I will stamp my foot on the ground and shake every house in Tuckhabarchee." The Creeks took the prophesy seriously and counted the days expecting that Tecumseh should reach Detroit by December 16, 2011. On the morning of December 16, the earth shook violently, and the Creek village was leveled.

According to Feldman (2005), those asleep in New Madrid on the morning of December 16 first heard the sound of a distant rumble like thunder or a deafening crashing sound like heavy artillery before being thrown from their beds by intense ground shaking. People fled their homes, which shook and jumped. The air smelled of a sulfurous vapor that was chocking to breathe. A man rushed back to his house to retrieve an infant only to be knocked to the ground by a second large shock. In his account, "We were all thrown to the ground. It was so dark that we could see only when the pale, sickly flashes of lightning illuminated the scene, and by the aid of it I saw the people all prostrated on the ground." Trees swayed like saplings and snapped crashing to the ground. River birds flew aimlessly screeching in terror, some landing on peoples' head and shoulders for comfort. After being flung to the ground several time, the man succeeded in rescuing his crying infant. Aftershocks continued through the night as people huddled in the cold streets.

A strong aftershock at 7:15 a.m. shook the ground and then turned into a series of hard vertical jolts. These jolts leveled the settlement of Little Prairie some thirty miles down river from New Madrid. Feldman (2005) quoted Little Prairie resident Godfrey Lesieur, eight at the time, who saw the ground, "rolling in waves of a few feet in height, with a visible depression between. By and by those swells burst, throwing up large volumes of water, sand, and a species of charcoal." Another resident, James Fletcher saw a granary and a smokehouse fall into a fissure and disappear. When the fissure closed, the buildings were permanently buried.

The first steamboat to travel the Ohio and Mississippi rivers, the *New Orleans*, was on its madden voyage to New Orleans in December of 2011. On December 15, those aboard the ship were awakened by the 2:15 a.m. earthquake. The size of the boat saved it from sinking in the disturbances on the river. The next morning as aftershocks continued, those on the steamboat sat calmly at breakfast, while watching trees on the bank "swaying as if in a high gale although, in fact, there was on wind blowing. They watched as an enormous section of riverbank suddenly tore away and dropped into the river." As the boat approached New Madrid, earthquake induced waves lifted the boat, making many passengers seasick. Uprooted trees filled the river channel, so that the pilot kept the steamboat in the middle of the river to avoid as many trees as possible. When they reached New Madrid in the afternoon, the entire town had dropped 15 feet down to the level of the river and was in shambles. The ground was rent by hundred-foot-long chasms, and people and animals wandered about in a daze. So many residents hailed the ship to board that their number was too large to be accommodated. The ship could only turn a deaf ear to the doomed town. By a twist of fate, the towns residents benefitted from the disasters of others, who abandoned their flatboats to the river during the earthquake. The river deposited unmanned boats full of supplies on New Madrid's shores, with meat, flour, cheese, butter, and apples.

After passing New Madrid, the *New Orleans* no longer anchored the shoreline, but rather anchored to the many islands in the river. One night when anchored to Island 32, the 32nd island below the mouth of the Ohio, the passengers heard loud banging against the side of the ship. In the morning, the steamboat was in the river with no island in sight, as if it had slipped anchor and floated down stream. However, the river-savvy pilot recognized landmarks on the bank. The boat had not moved, but the island came apart in the night tremors and was carried downstream with its trees by the current.

Much of the preceding account of the December 15, 1811, New Madrid earthquake and aftershocks is form Feldman's (2005) Chapter 15, entitled "All Nature was in a State of Dissolution." Chapter 16, concerning the New Madrid earthquakes of January 23 and February 7, 1812, is entitled "A Real Chaos."

Feldman's (2005) historical narrative included accounts from Audubon and Nolte. The New Madrid earthquake of January 23, 1812, occurred around 9:00 a.m. local time. In January of 1812, John J. Audubon and Vincent Nolte (who would later arrange for Audubon's first edition work in England) travelled down the Ohio on one of Nolte's flatboats to a landing near Cincinnati, then travelled by horse to Cincinnati where they went their separate ways. On the morning of January 23, Nolte was travelling through the vast forest between Frankfort and Louisville when his horse suddenly stopped as if struck by lightning. Nolte then noticed the trees to move strangely and wave about. When Nolte spurred his horse on, the horse obeyed the spur but again stood still in terror and "finally advance in a tremor" It was some time before the horse regained its pace.

Figure 691. Locations of Island 9 and Island 10 on the Mississippi River in the February 7, 1812, earthquake (showme.net/~fkeller/quake/mississippi_river_ran_backward.htm). Image 2605.

Audubon was traveling in the Barrens of Kentucky when he noticed a darkness rising from the west like gathering storm. He decided to stop at a house of a friend, then after traveling about a mile he heard "the distant rumble of a violent tornado," and spurred his horse to increased his pace, but the horse slowed to almost a standstill and carefully paced as if walking on ice. Audubon considered dismounting and walking his horse when the animal hung its head, spread its legs so as not to fall, and moaned piteously. Audubon feared the horse was about to die, but before he could dismount, the trees and bushes began moving from the roots up , and the ground rose and fell "in successive furrows, like the ruffled waters of a lake."

After the January 23 earthquake, Vincent Nolte resumed his trip to New Orleans and had the misfortune of arriving at New Madrid harbor on February 6, where he tied up along with about twenty other flatboats. At 3:45 a.m. the next morning, he was awake and working on a cartoon sketch when the earthquake hit. Nolte climbed on the roof of his boat and found it far from shore. Other boatmen untied their ropes from shore, fearing collapsing banks and falling trees. Nolte huddled with his crew to decide if they should do the same. Fearing the darkness and river debris, they decided to wait till daylight. The next morning they found New Madrid sunken, inundated, and destroyed, with some of its inhabitants visible among the ruins. Nolte's boat held to an island of fallen trees. The over boatmen were never heard from again.

Feldman (2005) cited the best account of the February 7 earthquake as from Matthias Speed, who was traveling to New Orleans. Speed's boat was tied to a willow bar across from Island 9, less than ten miles upstream

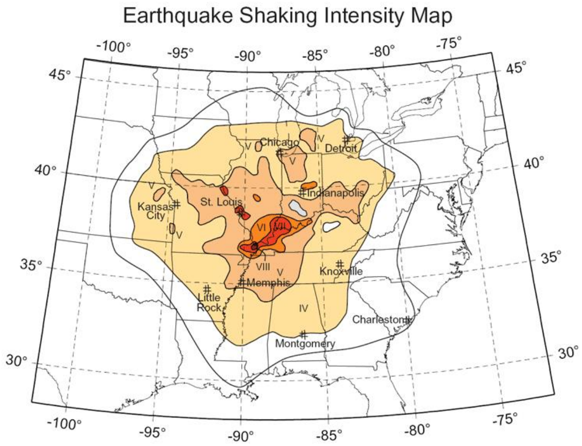


Figure 692. Isoseismal map of a magnitude 6.6 earthquake near Charleston, Missouri, in 1895 as measure on the Modified Mercalli scale (showme.net/~fkeller/quake/lib/charleston1895.htm). Image 2606.

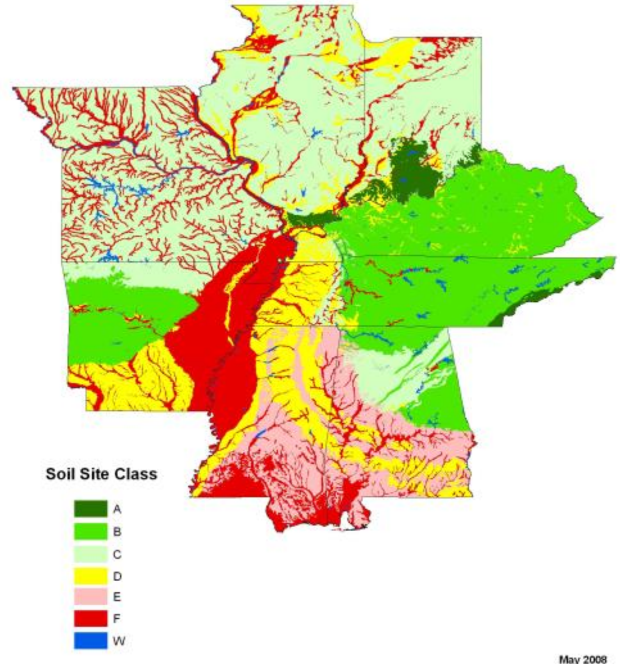


Figure 693. Soil Site Class Map (Soil Performance as a Function of Ground Shaking) correlated to Surficial Map Units for the seven CUSEC states, with A being least prone to damage by earthquake shaking and F being most prone. Soil Class **A** includes hard rock, **B** rock, **C** hard and/or very stiff soil, most gravel, **D** sands, silts, and stiff to very stiff clays, **E** soft to medium still clay with 40% moisture content, **F** soil vulnerable to potential failure or collapse under seismic loading. **W** is for water (FEMA New Madrid Catastrophic Planning Initiative, Illinois State Geological Survey). Image 2607.

from New Madrid. When the earthquake hit, Speed was awaken as his boat was thrown about and by a tremendous sound like that of heavy artillery coming from some subterranean source. Their island bar was sinking fast, so the crew cut loose and made for the middle of the river in swells so great that the boat was in danger of going under. The crew then tried to steer toward a light on shore, but landslides and falling trees made landing impossible. They drifted all night, and, at daylight, found themselves at Island 10, only four miles down river from where they started. Speed correctly determined that the river bed must have risen damming the current and slowing their down-river travel. Once past Island 10, the current rate picked up to a speed that propelled the boat to an uncharted waterfall (**Figure 691**). The crew could not stop the boat's momentum and went over the falls. They expected to perish at the bottom of the falls but fortunately survived and landed at New Madrid. The crew of a small boat traveling upriver, told of another even bigger waterfall downstream, so Speed sold his merchandise for pennies on the dollar, and made his way home by land.

One visible feature today of the February 7 earthquake is Reelfoot Lake, which was created by the earthquake. A witness to the lake's formation, in Feldman's (2005) account, was a French trapper named Pierre Nichol, who was hunting beaver at the time. When the earthquake hit, he had to grab a tree to keep from falling. The earth shook violently, the trees swayed and groaned, and then the ground cracked, and a large area of forest began to sink and sink until the tops of the largest trees dropped out of sight. The sinking was accompanied by a uplift of land that dammed Reelfoot Creek. Nichol testified, "In awe and wonderment, I stood reeling as one drunk with wine, and witnessed the birth of Reelfoot Lake." Today Reelfoot Lake is eighteen miles long, five miles wide, and up to 18 feet deep.

The largest earthquakes in the New Madrid Seismic Zone following 1812 include a M 6.0 earthquake on January 4, 1843 and a M 6.6 earthquake on October 31, 1895 (**Figure 692**).

According to a 2008 report by the U. S. Federal Emergency Management Agency, a serious earthquake in the New Madrid Seismic Zone could result in "the highest economic losses due to a natural disaster in the United States," with "widespread and catastrophic" damage across Alabama, Arkansas, Illinois, Indiana, Kansas, Kentucky, Mississippi, Missouri, Oklahoma, Texas, and Tennessee. In Tennessee, a M 7.7 earthquake would damage tens of thousands of structures and affect vital infrastructure. The death toll of such an earthquake is estimated to be in the many thousands with more than 4,000 fatalities in Memphis alone. An earthquake of this magnitude would also cause considerable damage in Mississippi. **Figure 693** shows soil performance as a function of ground shaking for the seven CUSEC

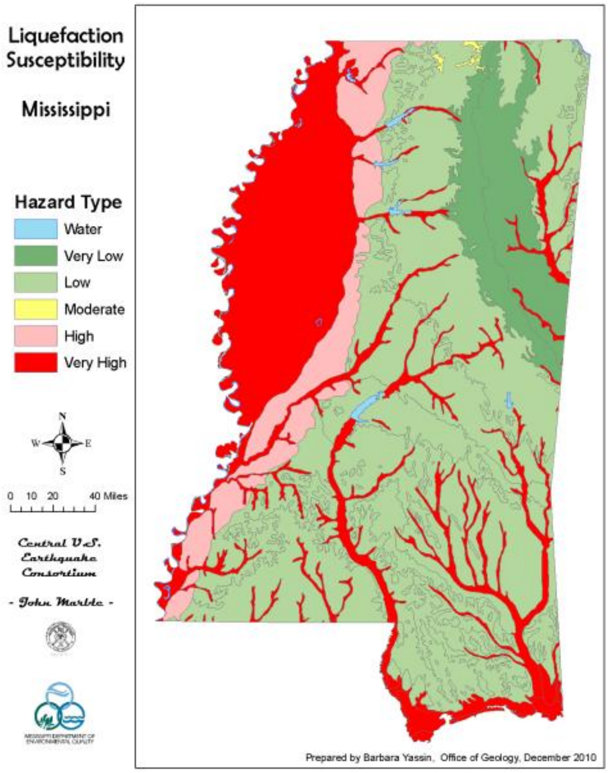


Figure 694. Mississippi map of soil susceptibility to liquefaction by earthquake shaking. Most prone (very high) to liquefaction areas are the alluvial soil of the Mississippi River floodplain and the floodplains of rivers and steam. The second most prone (high) is the loess soil of the Loess Hills, the third most prone (moderate) are patchy areas of Tertiary formations in northcentral Mississippi. On the low end of the spectrum and nest to the least prone (low) is the generally sandy "bedrock" soil that covers much of the state, and the least prone (very low) are the Cretaceous chalk and marls that comprise the Black Prairie in northeastern Mississippi. Image 2608.

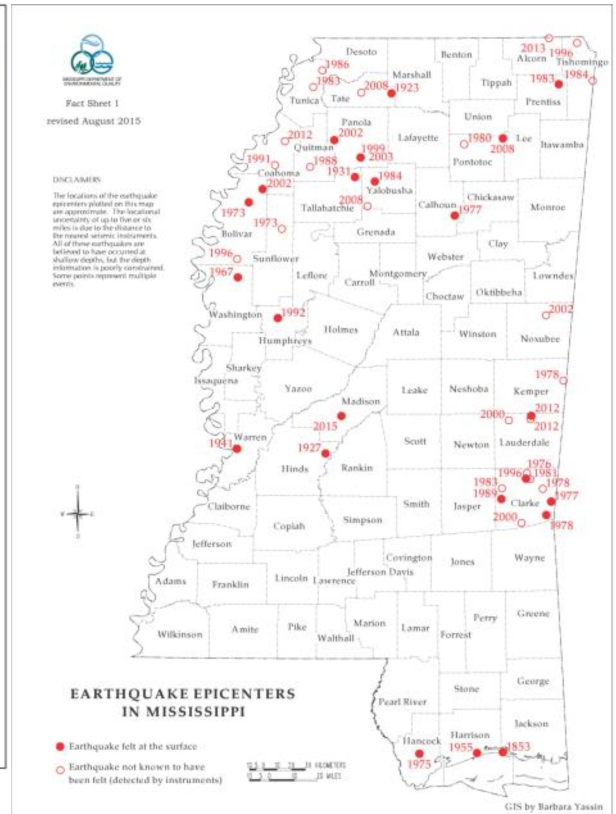


Figure 695. Earthquakes originating within Mississippi. Image 2609. From MDEQ Office of Geology Fact Sheet 1 by Michael B. E. Bograd, 2015.

states. The average shear wave velocity in Soil Class A is greater than 5,000 feet per second, while in Soil Class E is less than 600 feet per second The slower the shear wave velocity, the greater the shaking. **Figure 694** shows areas of Mississippi ranked by soil susceptibility to liquefaction by earthquake shaking. This map will be used in emergency management in predicting areas of most earthquake damage and planning staging areas for responders and field medical centers in areas least likely to receive damage from aftershocks. Alluvial soils in river floodplains are water saturated and poorly compacted a95 most susceptible to liquefaction. **Figure 681** shows earthquakes with epicenters in Mississippi.

EARTHQUAKE RISK

The map in **Figure 681** indicates that earthquakes have occurred throughout Mississippi. It is expected that earthquakes of low magnitude will continue to occur. Many earthquakes in neighboring (and distant) states have been felt in parts of Mississippi. However, the greatest risk to Mississippi from earthquakes is from a strong earthquake in the New Madrid Seismic Zone, the southern end of which is about 40 miles from the northwest corner of Mississippi. The great New Madrid earthquake series of 1811-1812 included at least four shocks strong enough to shake northern Mississippi at damaging intensities and be felt throughout the state. The 1843 earthquake at the southern end of the zone shook the northern third of Mississippi strongly enough to cause damage. People in Mississippi should take precautions for another strong earthquake on the New Madrid Seismic Zone.

Fact Sheet 1. Earthquakes in Mississippi by Michael B. E. Bograd, 2015. This is a list of earthquakes originating, or with epicenters within the State of Mississippi. Given are the date, location, whether or not it was felt, maximum intensity (in Modified Mercalli Intensity scale of 1-XII), and magnitude (a relative measure of the energy released).

September 11, 1853 - Biloxi, felt

March 27, 1923 - Wyatte, Tate Co., intensity IV
November 13, 1927 - Jackson, intensity IV
December 16, 1931 - Batesville-Charleston area, intensity VI-VII, mag. 4.7, damage in northern Miss., felt over 65,000 square miles in Miss., Ala., Ark., Tenn., and Mo.
June 28, 1941 - Vicksburg, intensity III-IV
February 1, 1955 - Gulfport, intensity V, felt along the Coast
June 4, 1967 - Greenville, intensity VI, mag. 3.8, felt over 25,000 square miles in Mississippi, Arkansas, Louisiana, and Tennessee
June 29, 1967 - Greenville, intensity V, mag. 3.4, felt in 3 counties
January 8, 1973 - Sunflower County, not felt, mag. 3.5
May 25, 1973 - Bolivar County, felt
September 9, 1975 - Hancock Co., intensity IV, mag. 2.9
October 23, 1976 - northern Clarke County, not felt, magnitude 3.0
May 3, 1977 - southeastern Clarke County, intensity V, magnitude 3.6
November 4, 1977 - Vardaman, Calhoun Co., intensity V, magnitude 3.4
January 8, 1978 - Kemper County-Alabama border, not felt, magnitude 3.0
June 9, 1978 - eastern Clarke County, not felt, mag. 3.3
December 10, 1978 - southeastern Clarke County, intensity V, magnitude 3.5
October 12, 1980 - northwestern Pontotoc County, not felt, magnitude 2.1
February 15, 1981 - Clarke County, not felt, magnitude 2.4
January 29, 1983 - northeastern Prentiss County, not felt, magnitude 2.4
February 5, 1983 - northeastern Prentiss County, intensity V, magnitude 2.9
April 25, 1983 - Tunica County, not felt, magnitude 1.6
May 30, 1983 - western Clarke County, not felt, mag. 2.4
March 23, 1984 - Tishomingo County-Alabama border, not felt, magnitude 2.0
September 24, 1984 - northwestern Yalobusha County, felt, magnitude 2.5
May 11, 1986 - northeastern Tunica Co., not felt, mag. 1.6

August 1, 1988 - Quitman County, not felt, magnitude 2.1
August 23, 1989 (2 events) - Pachuta, Clarke County, felt
August 25, 1989 - Pachuta, Clarke County, felt
November 26, 1989 (2 events) - Pachuta, Clarke Co., felt
February 11, 1991 - Clarksdale, Coahoma Co., not felt, magnitude 2.7
December 11, 1992 (2 events) - Belzoni, Humphreys County, both felt, first quake was magnitude 2.4
March 25, 1996 (2 events) - Clarke County, felt in Quitman and much of Clarke County, mag. 3.5; an aftershock of mag. 2.5 was felt about 30 minutes later
May 13, 1996 - northern Tishomingo Co., not felt, mag. 2.7
August 11, 1996 - southern Bolivar Co., not felt, mag. 3.1
Feb. 24, 1999 - southern Panola County, int. IV, mag. 2.8
January 28, 2000 - Shubuta, Clarke Co., not felt, mag. 2.7
October 10, 2000 - northwestern Lauderdale County, not felt, magnitude 2.3
January 6, 2002 - near Brooksville, Noxubee County, not felt, magnitude 2.2
August 11, 2002 - western Panola County, felt, mag. 2.8
October 26, 2002 - northern Bolivar County, felt, mag. 3.1
February 26, 2003 - Courtland, Panola Co., felt
January 20, 2008 - southwestern Yalobusha County, not felt, magnitude 1.7
May 10, 2008 - Belden, Lee Co., int. IV, magnitude 3.1
June 2, 2008 - near Senatobia, Tate Co., not felt, mag. 2.2
July 27, 2012 - Meridian Station, Lauderdale Co., felt, magnitude 2.1
July 29, 2012 - Meridian Station, Lauderdale Co., not felt, magnitude 1.6
October 9, 2012 - Jonestown, Coahoma Co., not felt, magnitude 2
August 30, 2013 - near Corinth, Alcorn Co., not felt, magnitude 2.0
May 2, 2015 (2 events) – S. Madison Co., both felt, magnitude 3.2 and 3.0
June 29, 2015 – S. Madison Co., felt, magnitude 3.2
Aug. 17, 2015 – S. Madison Co., felt, magnitude 2.6

SOURCES

The listings were compiled from published catalogs of earthquakes. The more recent, instrumentally recorded locations were taken from publications of the U.S. Geological Survey, National Earthquake Information Center, and the Center for Earthquake Research and Information at the University of Memphis.

Quaternary Climate Change. Submerged forest south of Gulf Shores, Alabama. The stumps and logs of an ancient cypress forest lie ten miles off the Alabama coast south of the Fort Morgan peninsula. The tree trunks and stumps line the margin of an ancient Mobile-Tensaw Delta river channel (**figures 696-697**). When first made known by fishermen shortly after Hurricane Katrina, the forest was thought to be 12,000 old when sea level was about 60 feet lower than today following the last (Wisconsinan) ice age (Raines, 2012).

Later, when the wood was tested using the Accelerator Mass Spectrometer Radio-Carbon Dating at the Lawrence Livermore National Laboratory, it was found to be "radiocarbon dead," meaning the wood contained no detectable carbon 14, and for this reason was older than 50,000 years. Vibracores through sediments covering the buried forest taken by Louisiana State University were able to obtain wood samples with a radio carbon age of 42,000 to 45,000 years, placing the ancient forest in the ballpark of 50,000 to 60,000 years. At this time, sea level was about 400 feet lower than today, and the shoreline was 30 to 60 miles further offshore. The cypress forest was on this now inundated zone some miles back of the shoreline, as cypress trees cannot tolerate saltwater. LSU paleoclimatologist Kristine DeLong placed the forest in a period called Marine Isotopic Stage 3, a time going into full glacial conditions but not quite there yet. The climate on the Gulf Coast at that time was colder and windier (Raines, 2017).

Pollen analysis of the LSU cores indicated that the submerged forest was more like that found today in the colder climate of North Carolina. The cores penetrated three feet of recent sand, then three feet of sand and marine clay, and then surprisingly into a perfectly preserved peat for about two feet (**Figure 698**). Pollen indicated the forest was a mix of cypress, alder, and oak, an assemblage like that of the Atlantic Coastal Plain Blackwater Levee/Bar Forest on the coasts of North and South Carolina.

A study of the tree-ring chronology (dendrochronology) at the Dendron Lab of the University of Southern Mississippi by Grant Harley matched the chronologies of ten usable wood samples to create a floating composite chronology of 500 years. Some of the trees at the site were ten-feet in diameter and thirty feet in circumference. Pollen in the peat core showed the lower peat to be dominated by tree

Figure 696. Raising a tree log from the submerged forest off the Alabama coast. From Raines, 2017. Image 2610

Figure 697. Collecting wood samples from Alabama's submerged forest. From Raines, 2017. Image 2611.

Figure 698. Vibracore containing the peat deposit overlying the submerged forest. Ancient pollen in the peat shows a transition from forest at the bottom of the core to marsh grasslands at the top. From Raines, 2017. Image 2612.

pollen and the upper peat to be dominated by grass pollen such as sedge. This sequence indicates that rising sea level, at a rate of some 75 feet per thousand years, killed the forest and

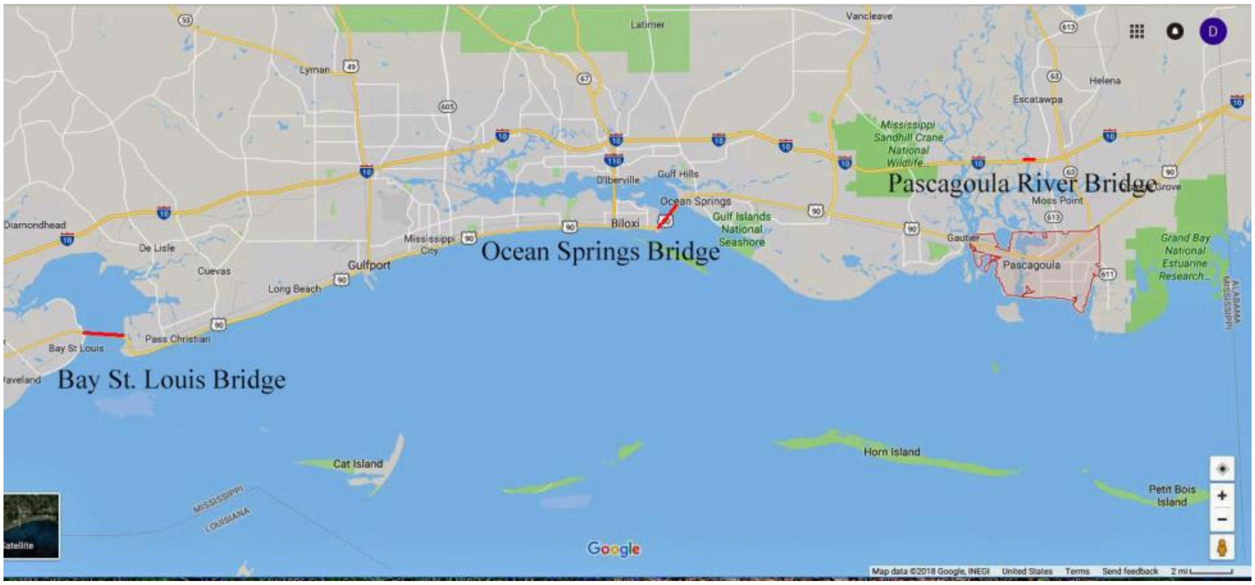


Figure 699. Three bridges marked in red span Bay St. Louis, Biloxi Bay (Ocean Springs Bridge), and the Pascagoula River and cross Pleistocene valley fill coastal deposits.

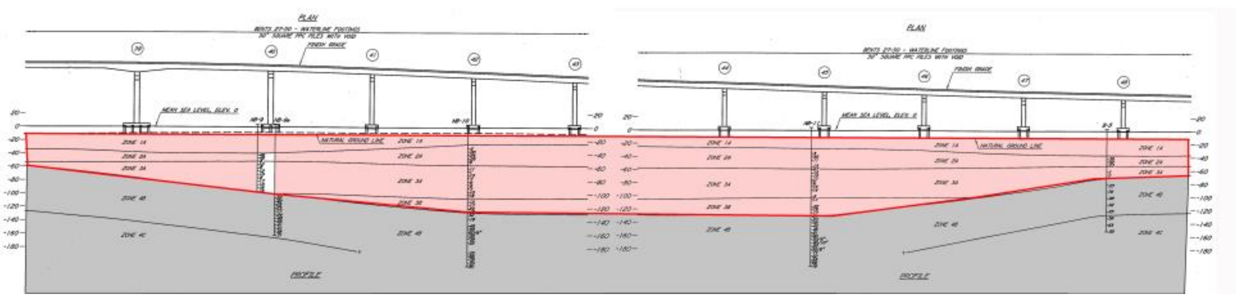


Figure 700. Coastal valley fill deposits (pink) in a Pleistocene valley under the midsection (bents 39-48 of 77 bents) of the Bay St. Louis Bridge as shown on the geotechnical report for bridge replacement issued April 2006.

buried it beneath marine muds. There it stayed for 50,000 years until excavated by the waves and currents created by Category 5 Hurricane Ivan when it crossed the Gulf with up to 98-foot-tall waves (the largest ever measured) before making landfall in Gulf Shores, Alabama, as a Category 3 storm. At the time, Ivan set the world record of 33 (with 32 consecutive) six-hour periods of intensity at or above Category 4 strength; while in the Gulf it was calculated to have eyewall wave heights of 131 feet.

Buried Pleistocene River Valleys along the Mississippi Gulf Coast. Geotechnical reports for three bridges along the Mississippi Gulf Coast show deep Pleistocene valley fill coastal deposits (**Figure 699**). **Figure 700** shows coastal valley fill deposits (in pink) to a depth of 130 feet below sea level in the midsection of the St. Louis Bay bridge. Soil zones 1-3 in the description at right are listed as coastal deposits, and Zone 4 is listed as the Pascagoula Formation. This information is from The Final Geotechnical Report Packagae 1, Bridge Replacement on US 90 Across St. Louis Bay, Hancock and Harrison Counties, Mississippi, for MDOT by HNTB Corporation, April 2006.

SOIL ZONE DESCRIPTIONS

ZONE 1 COASTAL DEPOSITS

ZONE 1A - VERY SOFT TO MEDIUM STIFF, LIGHT GRAY TO DARK GRAY, TAN, SILTY CLAY AND CLAY, SLIGHTLY SILTY AND SANDY WITH SANDY CLAY AND SAND POCKETS

ZONE 1B - LOOSE TO MEDIUM DENSE, LIGHT GRAY TO GRAY, TAN, FINE SAND, SLIGHTLY SILTY AND CLAYEY WITH SOME SHELL FRAGMENTS

ZONE 2 COASTAL DEPOSITS

ZONE 2A - VERY LOOSE TO DENSE, LIGHT GRAY TO GRAY, TAN, FINE TO MEDIUM SAND, SLIGHTLY SILTY, SHELL FRAGMENTS, ORGANICS, TRACE OF GRAVEL

ZONE 3 COASTAL DEPOSITS

ZONE 3A - LOOSE TO MEDIUM DENSE, LIGHT GRAY TO GRAY, TAN, SILTY FINE SAND

ZONE 3B - MEDIUM DENSE, LIGHT GRAY, FINE SAND AND SILTY SAND, TRACE OF GRAVEL

ZONE 4 PASCAGOULA FORMATION

ZONE 4A - MEDIUM STIFF TO HARD, LIGHT GRAY TO GRAY, TAN, GREEN, SILTY CLAY, SANDY CLAY AND CLAY, SAND SEAMS AND SHELL FRAGMENTS

ZONE 4B - MEDIUM DENSE TO VERY DENSE, LIGHT GRAY TO GRAY, SILTY FINE TO MEDIUM SAND, WITH GRAVEL AND CLAY LAYERS

ZONE 4C - VERY DENSE, LIGHT GRAY TO GRAY, TAN, GREEN, FINE TO MEDIUM SAND, SLIGHTY SILTY, TRACE OF GRAVEL

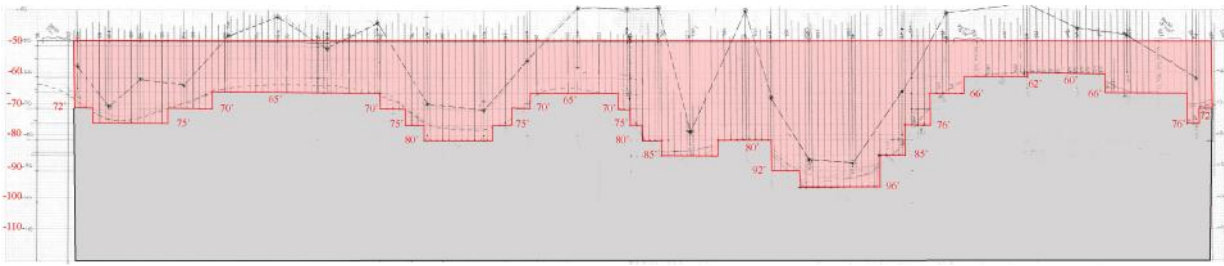


Figure 701. Depth of piles driven to competent bedrock/soil for the Ocean Springs Bridge. The top datum for the profile is a depth of 50 feet below sea level.

Figure 701 shows the depth of piles for the Ocean Springs bridge across the mouth of Biloxi Bay. Pleistocene valleys back filled with coastal deposits (in pink) can be see by the depth required to drive the piles into competent bedrock/soil. The deepest piles reach a depth of 96 feet. The straight datum at the top is 50 feet below seal level.

Figure 702 is a portion of the Geologic Map of Jackson County (Stewart and Starnes,

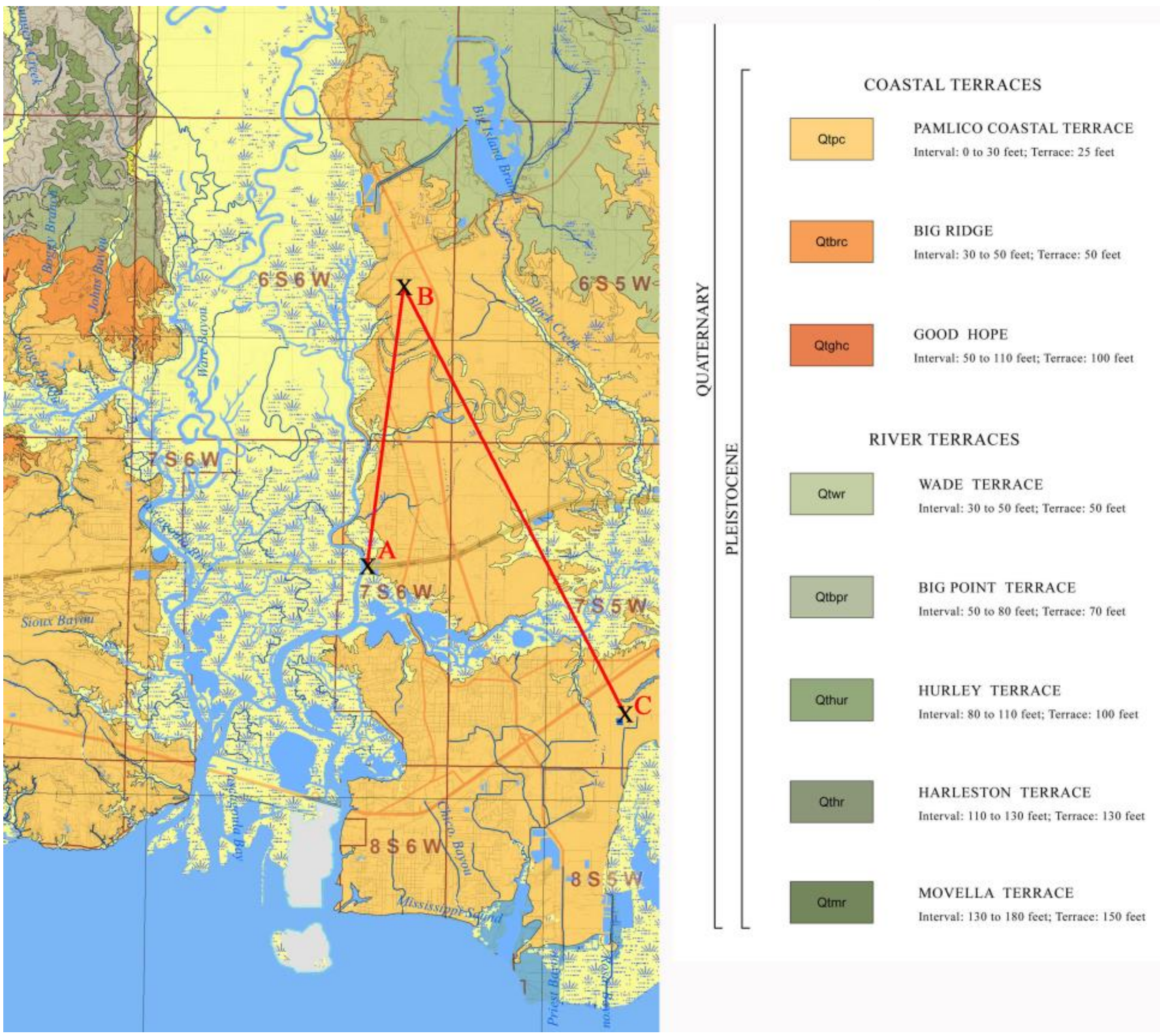


Figure 702. Geologic map of Jackson County, Mississippi, showing coastal and river terraces along the mouth of the Pascagoula River.. Site A is the soil profile of the east bank of the I 10 Bridge over the Pascagoula River.. Sites B and C are test holes in the Pamlico Coastal Terrace.

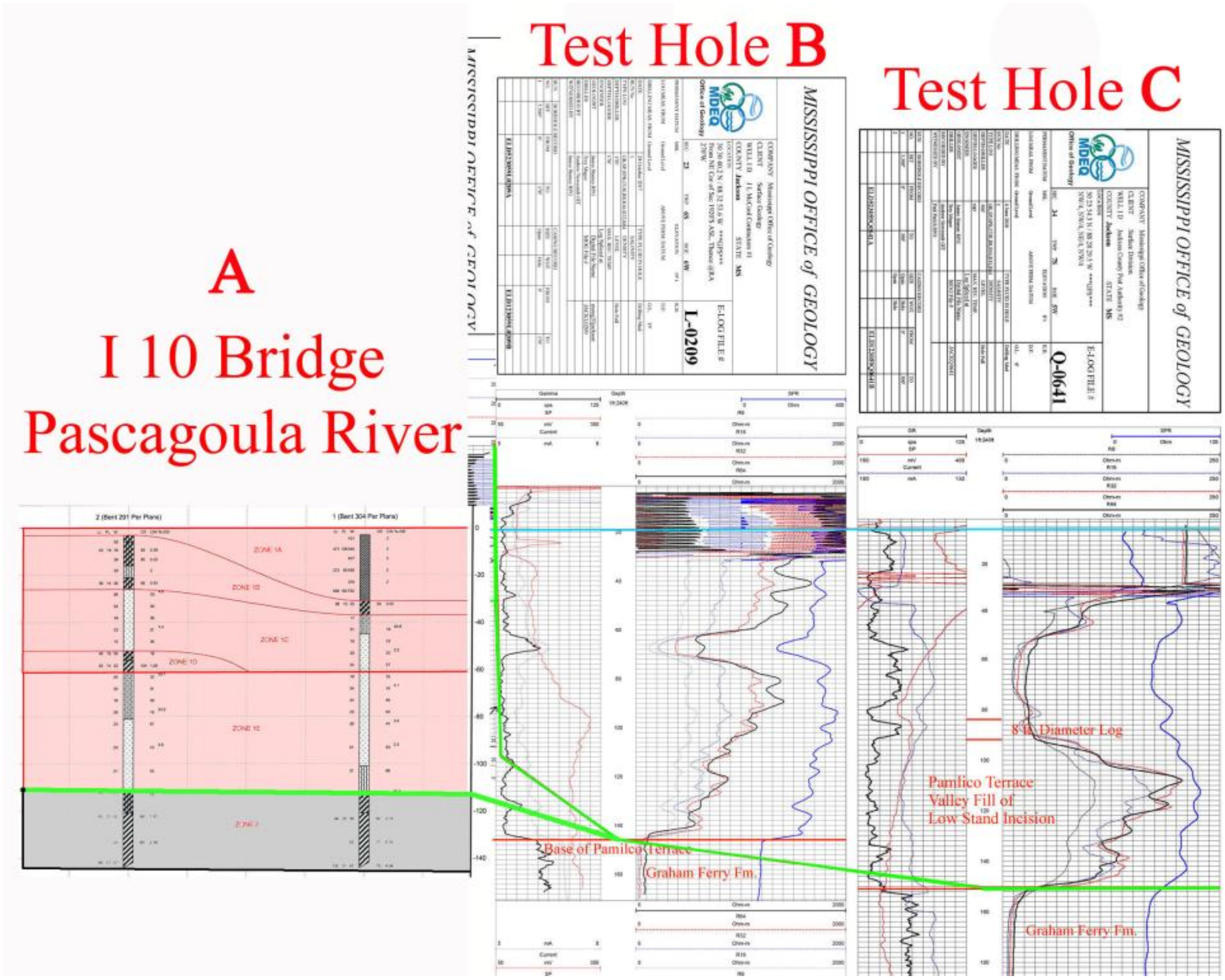


Figure 703. Cross section of valley fill deposits of the Pamlico Coastal Terrace in Jackson County, Mississippi. An eight-foot thick log was encountered at 82 to 90 feet below surface level in test hole C. Test hole geophysical log correlations are by James Starnes.

2017) showing coastal and river terraces. Sites labeled A, B, and C are associated with thick valley fill deposits in the Pamlico Coastal Terrace as shown in **Figure 703**. In **Figure 704**, the Pleistocene-Pliocene boundary is shown on the geophysical log from test hole C as held by Jonathan Leard.

Figure 705 at top shows unweathered pea gravel characteristic of the Graham Ferry Formation. At bottom, the figure shows the highly weathered tripolitic gravel of the Pamlico Coastal Terrace. In the middle from left to right is the contact of the Pascagoula River alluvium with clay of the Graham Ferry Formation at 35 feet below surface level, the Wade River Terrace contact with the Graham Ferry Formation at a depth of 75 feet below surface level, and a four-foot thick log encountered at a depth of 53 feet below the surface and 18 feet below sea level.

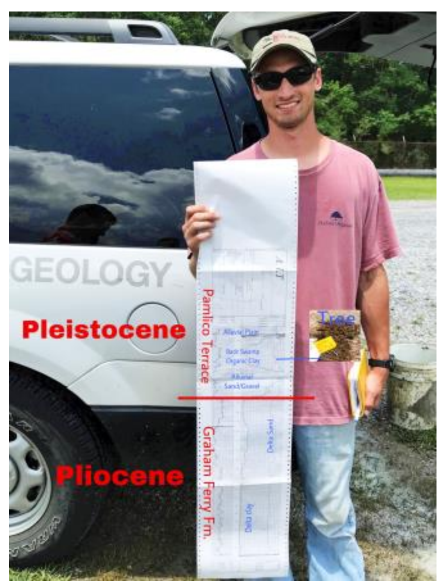


Figure 704. Jonathan Leard hold a copy of the geophysical log for test hole C, showing the Pleistocene-Pliocene boundary..

Figure 705. Test hole samples from Jackson County, Mississippi. At top is unweathered pea gravel from the Graham Ferry Formation. At middle left is the contact between the Pascagoula River alluvium and clay in the Graham Ferry Formation in the #1 MDWFP Cat Lake test hole. At middle middle is the contact of the Wade Terrace with the Graham Ferry Formation at 75 feet below surface level and 23 feet below seal level, where the terrace fill an ancient valley. At middle right are wood fragments of a four-foot thick log at a depth of 53 feet below the surface and 18 feet below sea level in Wade Coastal Terrace. At bottom is the highly weathered tripolitc gravel of the Pamlico Coastal Terrace from a depth of 50 to 60 feet below the surface..

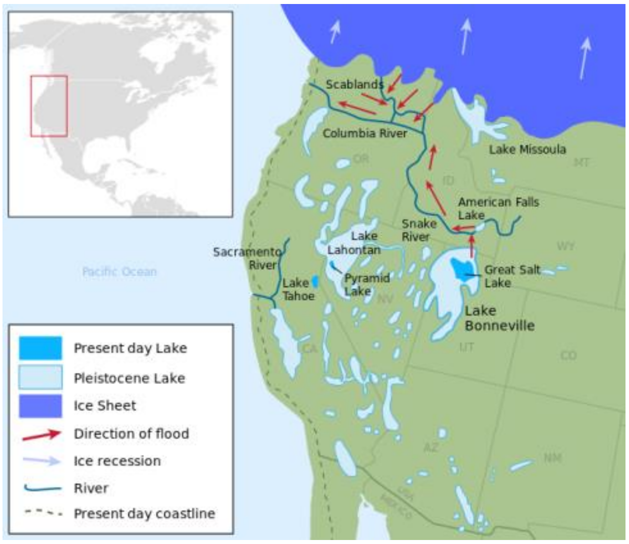


Figure 706. Pleistocene pluvial in the American West. Image from Wikipedia. Image 2613.

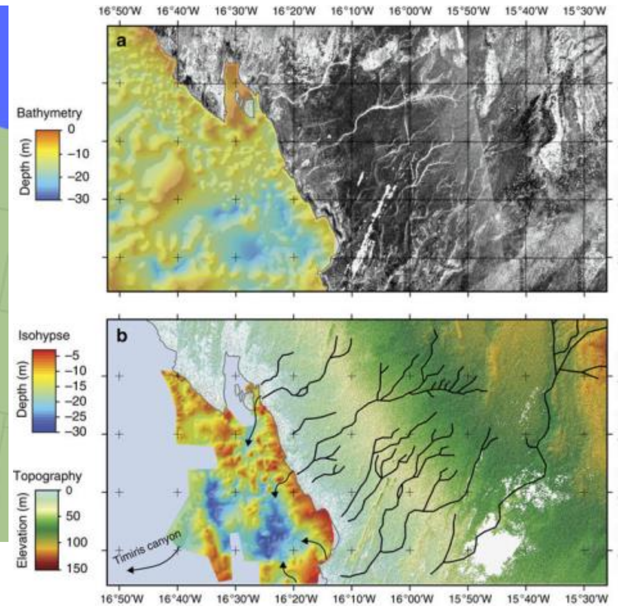


Figure 707. Radar imagery of river channels hidden beneath Saharan sands in coastal Mauritanai as taken by a Japanese Earth observation satellite. Image from Skonieczny et al., Nature Communications, 2015. Image 2614.

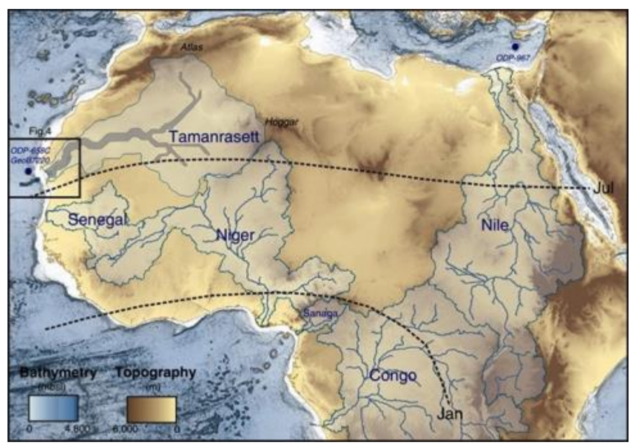


Figure 708. The main course of the proposed Tamanrasett River in northwestern Africa and the Cap Timiris Canyon off the West African coast. Image from Skonieczny et al., Nature Communications, 2015. Image 2615.

Pleistocene Pluvial Lakes in the American West. In the warmer or pluvial periods during times of glaciation, lakes formed in the landlocked basins of the American West (**Figure 706**). The desert west was transformed in the Pleistocene as warm air met cold air from the ice sheets, creating more precipitation than evaporation and forming lakes. These areas returned to deserts during interglacial periods.

Pleistocene and Early Holocene River Beds Beneath the Sand of the Saharan Desert. In 1957, French explorer Henri Lhote made the surprising discovery of cave paintings of giraffes and elephants in desert North Africa, leading him to recognize that the landscape was much more humid in the past. Now the Japanese Earth observation satellite, using radar imagery, has found river beds across the middle of the Sahara from the Atlas Mountains to the north and the Hoggar Mountains to the east and empting into the Atlantic Ocean of the west coast. This river system, proposed as the Tamanrasett, would be ranked as the 12th among the largest on Earth. As late as 7,000 years ago the Tamanrasett basin was covered by a green savanna inhabited by cattle, sheep, and goats. The mouth of the river channels on the African west coast align almost perfectly with a hugh submarine canyon off the coast of Mauritania (**figures 707-708**). The Cap Timiris Canyon is over a mile wide and half a mile deep in places (Sample, 2015).

Holocene Desertification. Figure 688 shows global areas experiencing desertification. Most of these area are along the expanding margins of already desert lands, including deserts in the American West, North Africa, South Africa, the Middle East, and Australia.

Abandonment of Ancestral Pueblo Cliff Dwellings in American West. What if New York city were abandoned by its population and remained uninhabited for hundreds of years. Does that sound unthinkable? However, this has happened to ancient civilizations due to climate change. Mesa Verde National Park in Montezuma County, Colorado, includes some 600 cliff dwellings. At the beginning of the 13th Century some 22,000 people lived in the plains west of Mesa Verde. A se-

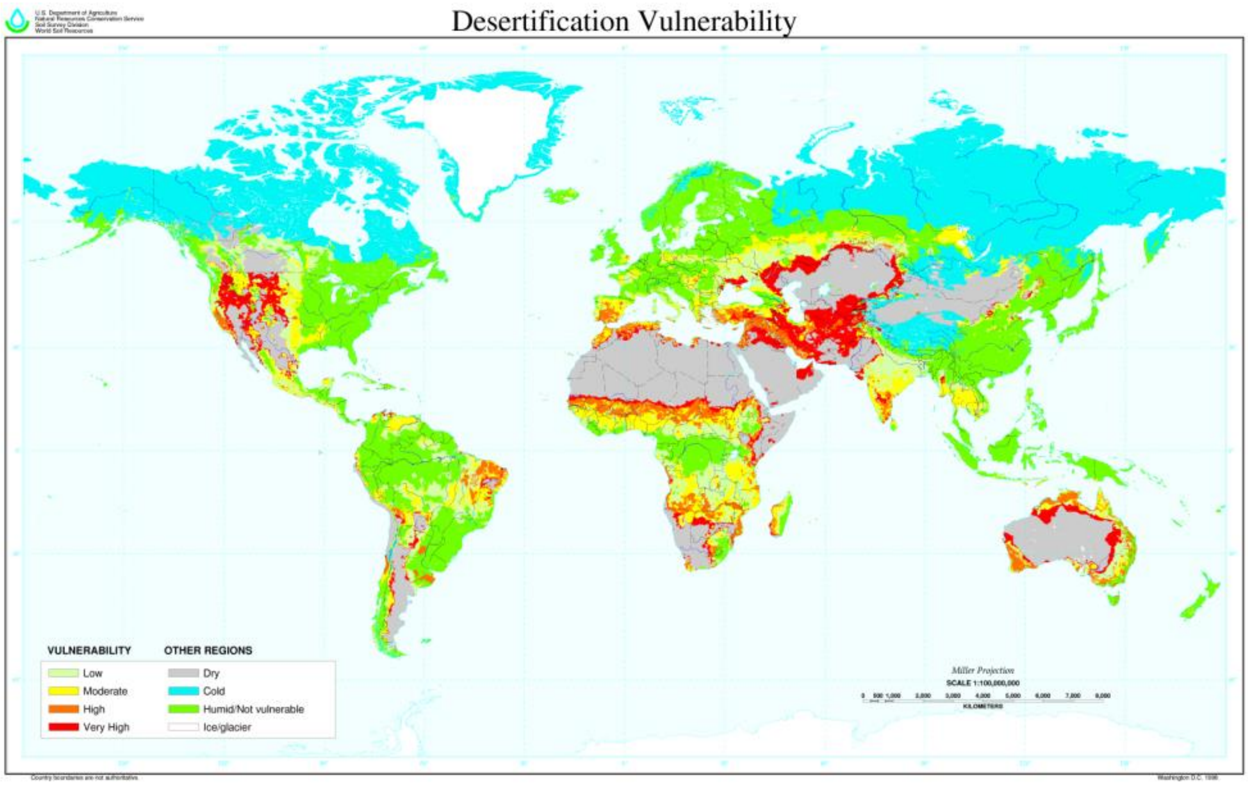


Figure 709. Red area labeled at Very High Vulnerability for desertification, are currently undergoing desertification, including the American West. Map by the U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Division, World Soil Resources. 1998. Image 2616.

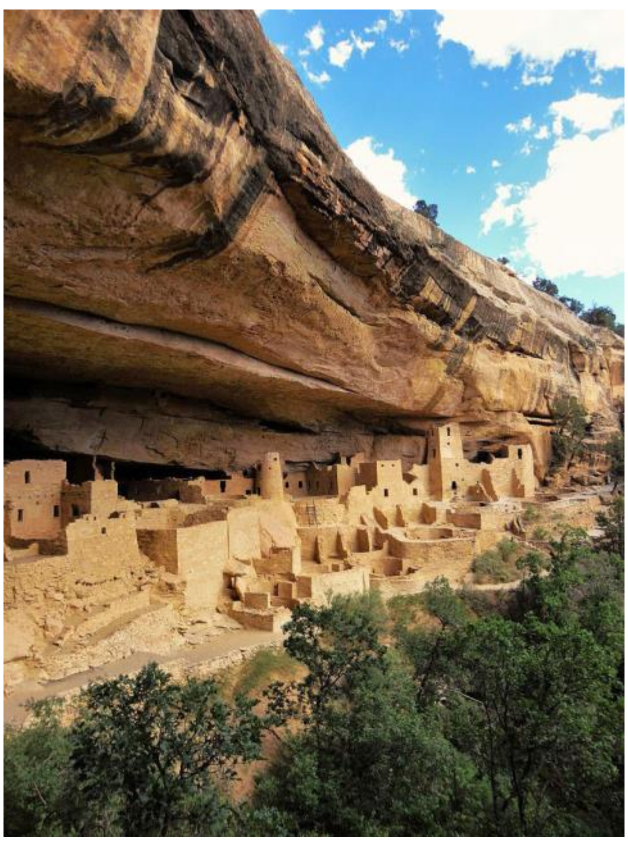


Figure 710. Cliff Palace is the largest cliff dwelling in Mesa Verde National Park. Image 2617.

vere dry period from 1276 to 1299 ended seven hundred years of continuous human occupation at Mesa Verde. The last inhabitants left the area in 1285 (**Figure 710**).

Collapse of the Mayan Civilization. Early Mayan settlement in Central America date to 2,000 B.C. Around 250 A.D., they began to build flourishing cites, temples, and palaces as their population peaked at a time called the Classic Period. Yet this period ended around 900 A.D. when almost all the major cities in the Mayan heartland of present-day northern Guatemala, Mexico, Belize, and Honduras had been abandoned (**Figure 711**).

The Pennsylvanian, Cretaceous, and Paleogene Climate Change Record in Mississippi. Mississippi is an important source of information on ancient climate change due to the state's excellent marine record preserved in formations of Pennsylvanian, Late Cretaceous, and Paleogene age. In the basement rocks of the Black Warrior Basin in northeastern Mississippi there are cyclothem deposits in the Pennsylvanian Pottsville Formation that record

Figure 711. Above. The Mayan city of Tikal in Guatemala was abandoned due to a combination of deforestation and drought. The final monument in Tikal was erected in 889 A.D., and by 950 A.D. the city was all but deserted. Picture from Wikimedia Commons/Shark. Image 2618.

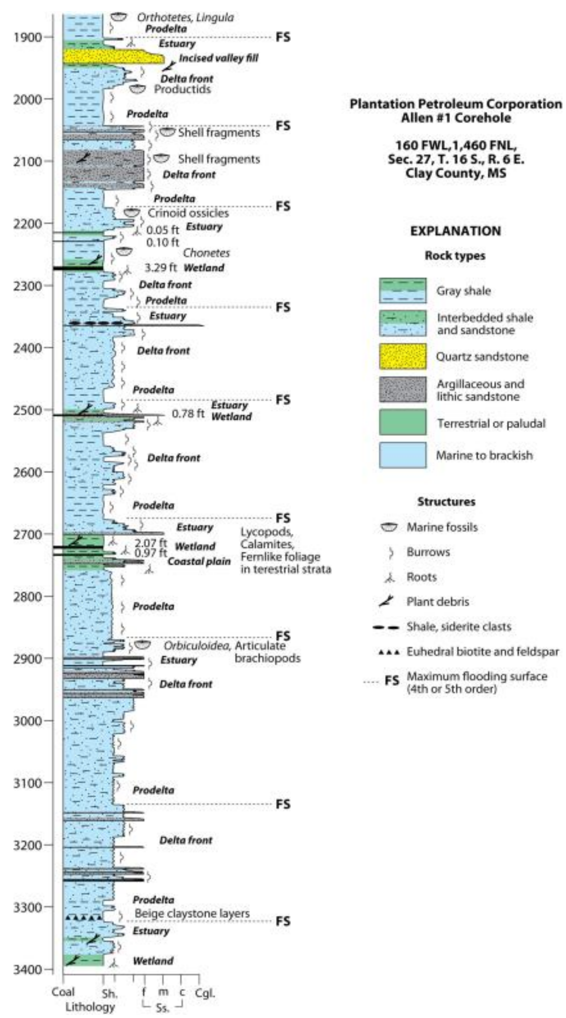


Figure 712. Right. Cyclothems in the depositional environments of the Pottsville Formation in Clay County, Mississippi. Figure by Jack Pashin. Image 2619.

successive rises and falls of sea level due to the waxing and waning of glacial ice in Gondwana at the South Pole (**Figure 712**). Coal measures in the Pottsville are punctuated by marine beds with brachiopod shells (**Figure 713**).

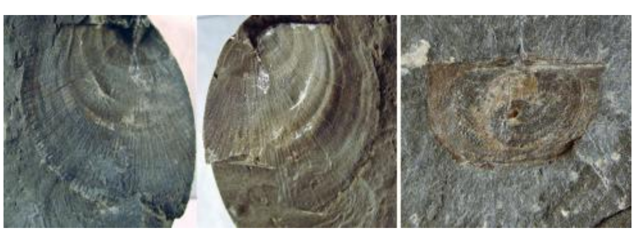


Figure 713. Brachiopod shells in the Pottsville Formation of the Plantation Petroleum Corporation Allen #1 Corehole Clay County, Mississippi. Image 2620.

Figure 714. George Phillips holding survey rod in front of a vertical joint plane in the Muldrow Member of the Demopolis Formation in the high wall of the Holcim Inc. Artesia Plant chalk quarry near Artesian in Lowndes County, Mississippi. Picture taken on August 24, 2007. Image 932.

Figure 715. Dark and light banded layers, indicating oxic and anoxic deposition, in the Muldrow Member of the Demopolis Formation in a freshly quarried high wall of the Holcim Inc. Artesia Plant chalk quarry near Artesia in Lowndes County, Mississippi. Picture taken on August 24, 2007. Image 933.

Figure 716. Cretaceous chalk cores from the Demopolis Formation at Shuqualak, Mississippi, in MDEQ's Core and Sample Library in Jackson. Image 2621.

Figure 717. Bedding planes in the Cretaceous chalk core from Shuqualak, Mississippi, in MDEQ's Core and Sample Library in Jackson. At left is the fossil pecten Neithea quinquecostata and at right are biotite crystals (black) from a volcanic eruption at Jackson 75 million years ago. Image 2622.

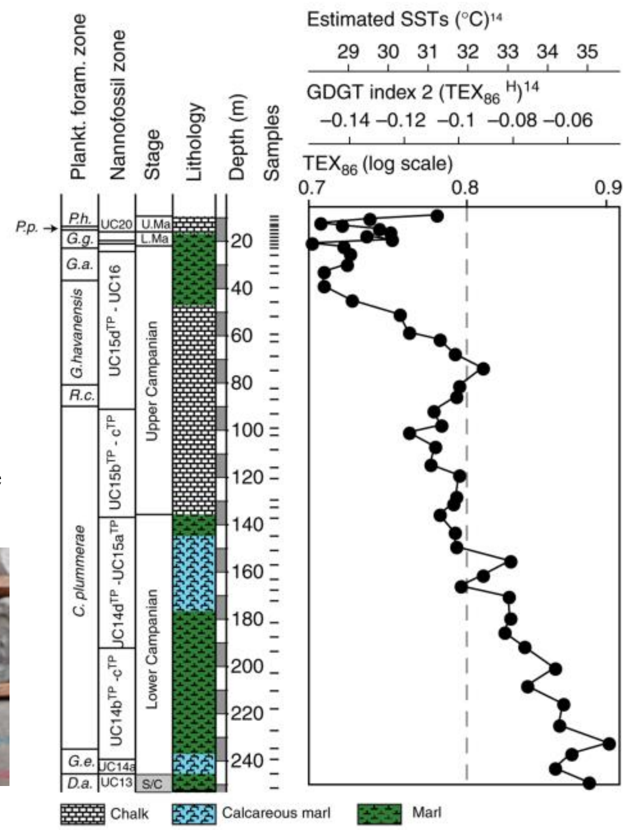


Figure 718. TEX86 data and calculated surface sea-water temperatures from the Shuqualak core from Linnert et al., 2014, Evidence for global cooling in the Late Cretaceous: Nature Communications, June 2014, 7 p. Image 2623.

Global Cooling in the late Campanian Stage of the Cretaceous in Mississippi. Cores through the Cretaceous chalk of the Mooreville and Demopolis formations of Late Cretaceous age (**figures 714-719**) in northeastern Mississippi hold valuable information on

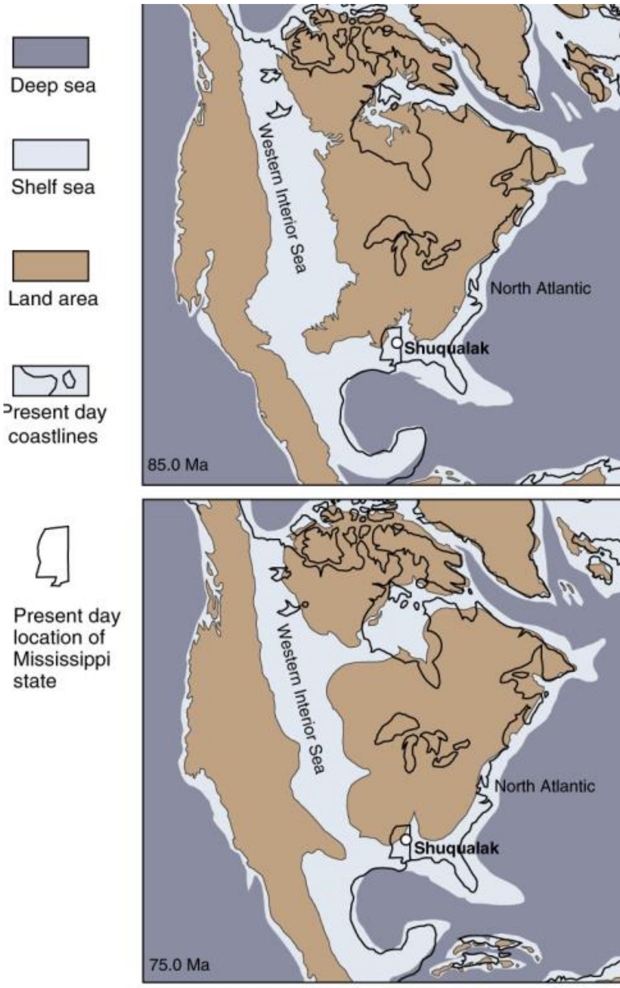


Figure 719. The Late Cretaceous sea that covered parts of North America at the time of chalk deposition at Shuqualak, Mississippi, at 85 and 75 million years ago from Linnert et al., 2014, Evidence for global cooling in the Late Cretaceous: Nature Communications, June 2014, 7 p. Image 2624.

Figure 720. Lauren O'Conner and Stuart Robinson of the University of Oxford sampling a Cretaceous chalk core from Shuqualak, Mississippi, at MDEQ's Core and Sample Library in Jackson on April 27, 2015. Image 2625.

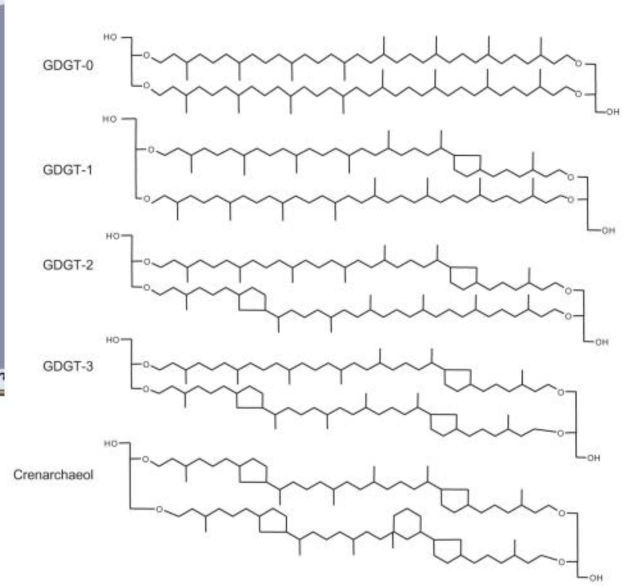


Figure 721. Crenarhaeol region-isomer. Structures of isoprenoid glycerol dibiphytanyl glycerol tetraethers (GDGTs), which are mainly biosyntheized by Marine Group I Crenarchaeota, one of the dominat prokaryotes in today's oceans. Different types of isoprenoid GDGTs contain 0-3 cyclopentane moieties and 4 cyclopentane moieties with additional cyclohexane moiety. The number of cyclopentane moieties increase with increasing temperature of the annual mean sea surface temperature (from Kim et al., 2010). Image 2626.

climate change at a time that dinosaurs inhabited lands north of the Artic Circle in Alaska.

Stuart Robinson and his Ph.D. graduate student Lauren O'Conner of the Department of Earth Sciences, University of Oxford, Oxford, England, sampled cores of Cretaceous chalk from Shuqualak, Mississippi, at the Core and Sample Library on April 27 - May 1, 2015 (**Figure 720**). An earlier study of these cores provided excellent data, and Robinson and O'Conner's visit was to sample the core at finer intervals. Using fossil molecules (TEX_{86}) of the distinct lipids of marine archaea bacteria as a proxy for seawater temperature, the cores showed a cooling trend during the Campanian Stage of the globally warm Late Cretaceous Period (**Figure 721**). Also in the Shuqualak cores were fossil shells and biotite mica ash from the eruption of the Jackson Volcano some 75 million years ago (**Figure 717**).

Paleocene Tropical Lateritic Paleosols in Mississippi. Today lateritic soils containing bauxite, the ore for aluminum, are found in the heavily leached soils of tropical rain forests. Yet ancient examples of lateritic soil and bauxite can be found in the Paleocene

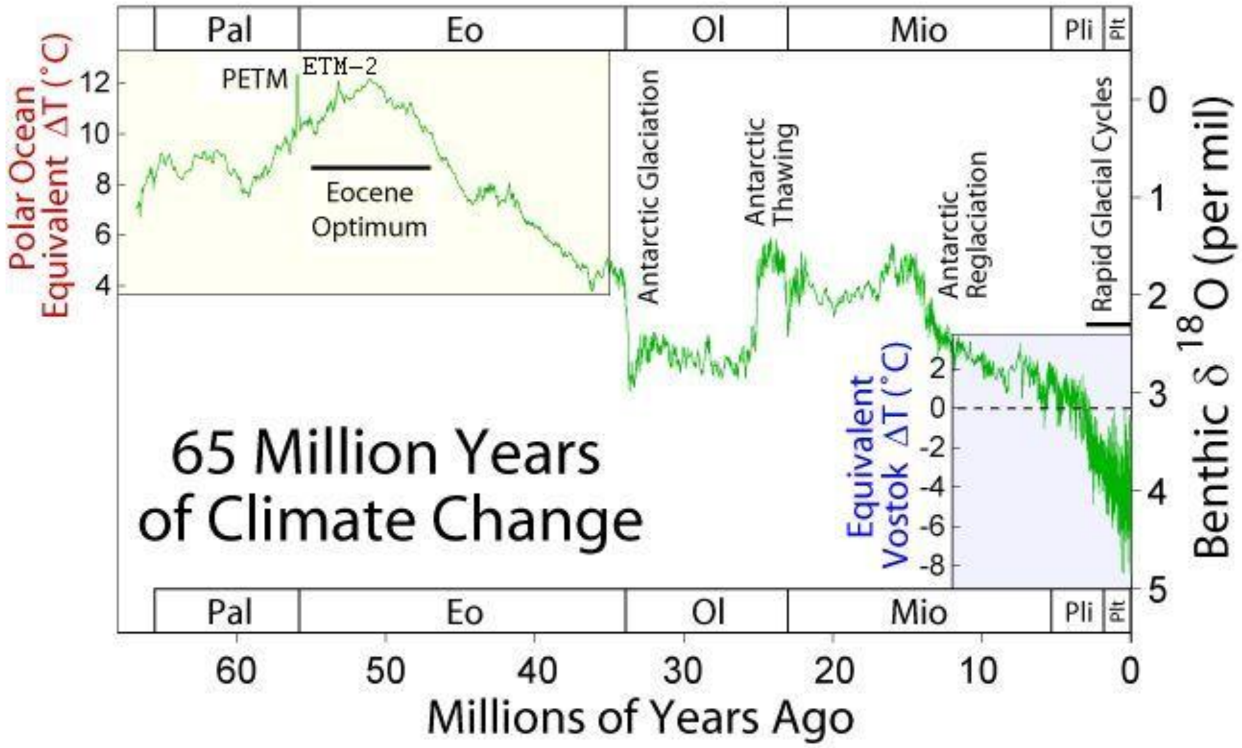


Figure 722. Climate change over the last 65 million year as compiled from the oxygen isotope composition of benthic Foraminifera, From Wikipedia: Paleocene-Eocene Thermal Maximum. Image 2628.

Figure 723. Paleocene lateritic paleosol. David Thompson at the contact of a pisolitic kaolinitic clay in the Coal Bluff Member and the overlying Gravel Creek Member in Section 15, T. 13 N., R. 15E., Noxubee County. Picture taken on October 7, 1992. Image 400.

Figure 724. Ron Rose looking at bauxite overlying a kaolintic clay in the weathered upper Oak Hill Member of the Nanafalia Formation in Pontotoc County, Mississippi. Picture taken by David Thompson. Image 2629,

sediments of Mississippi and Arkansas during a Paleocene warm period shown in **Figure 722**. In Mississippi, potentially commercial deposits of bauxite occur in the Oak Hill Member of the Naheola Formation in Benton and Tippah counties and in the overlying Coal Bluff Member of the Naheola in Pontotoc and Union counties. **Figure 723** shows David Thompson by a kaolinitic lateritic paleosol in the Coal Bluff Member of the Naheola Formation in Noxubee County. **Figure 724** shows Ron Rose by a bauxite deposit in Pontotoc County.

The Paleocene-Eocene Thermal Maximum (PETM). The PETM occurred at the Paleocene-Eocene boundary beginning about 55.5 million years ago and was a period

Figure 725. Chris Beard excavating the T-4 sand at the top of the Tuscahoma Formation at the Red Hot Truck Stop locality in Meridian, Mississippi. In the excavation face above are Early Eocene fossil-leaf-bearing clays of the Bashi lowstand deposit. Picture taken on September 28, 1994. Image 119.

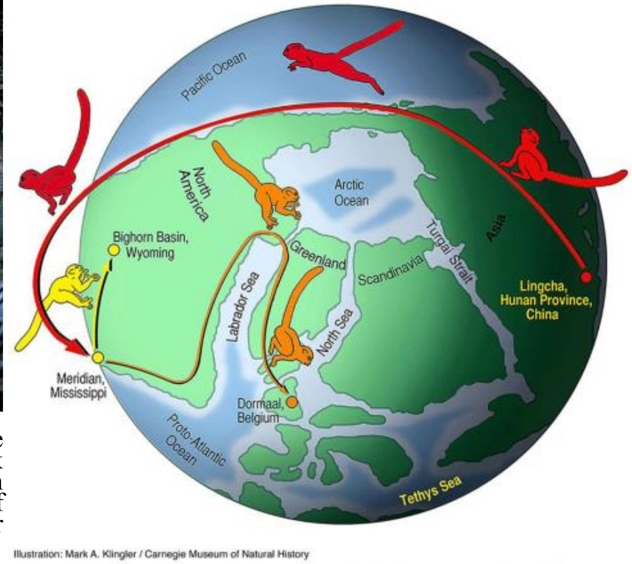


Figure 726. Migration route of early primates 55.5 million years ago from China, around the eastern Pacific and northern Gulf of Mexico to Meridian, Mississippi, and then north to Wyoming and east to Belgium by way of the North American east coast and Greenland (according to Beard, 2008). Image 1610.

of about 200,000 years when the global temperature was more than 8 degrees C warmer than the global average today. The onset of this event had an initial 5 degree C increase and was marked by a negative excursion in the carbon stable isotope ($\delta^{13}C$) record worldwide, with a large decease in the $^{13}C/^{12}C$ ratio of marine and terrestrial carbonates and organic carbon. The upper part of the PETM is present in the T4 Sand of the Tuscahoma Formation at Meridian, Mississippi, which contains the negative ^{13}C excursion and the expansion of the subtropical dinoflagellate *Apectodinium*. **Figure 725** showing the excavation of the T4 Sand at the Red Hot Truck Stop locality in Meridian Mississippi. This site contains shark, fish, crocodile, snake, and mammal remains, with 22 species of mammals including the second oldest primate *Teilhardina magnoliana*. During the PETM, this small primate crossed an Arctic land bridge from Asia to North America (**Figure 726**).

The Early Eocene Optimum. Muttoni and Kent (2007), placed the peak of Eocene chert occurrences in deep sea core at about 50 million years ago and as "coincident with the time of highest bottom water temperature of the Early Eocene Climate Optimum (EECO). Weaver and Wise (1974) documented siliceous microfossils in the Tallahatta Formation and correlated these fossils and associated cristobalite deposits to a worldwide period of Eocene chert formation labeled Horizon A as represented in "portions of all major ocean basins explored to date by Deep Sea Drilling." The EECO can be seen while traveling Interstate 20 eastward just before Meridian, Mississippi. Here vertical cuts in Tallahatta claystones show the white siliceous rock for which the formation was named, a Native Amerian name meaning "white rock" (**Figure 727**).

Figure 727. Tallahatta Formation in south-facing road cut on Interstate 20 west of Meridian at Lost Gap in Lauderdale County. Picture was taken in June of 1974. Image 227.

The Middle Eocene Optimum. The Middle Eocene Optimum was a warm period that began around 41.5 million years ago and lasted for 600,000 years. At this time, atmospheric carbon reached a maximum of 4000 ppm, the highest value in the Eocene. At the end of this event was a cooling trend through the Late Eocene. By the end of the Eocene carbon dioxide concentration deceased to around 750-800 ppm. During the Middle Eocene crocodiles and tropical plants such as palm trees existed at higher latitudes.

Figure 728. David Williamson standing on the Dobys Bluff Tongue's type locality on the bank of the Chickasawhay River at Dobys Bluff (MGS locality 26), where the overlying Archusa Marl Member of the Cook Mountain Formation forms a vertical wall. Picture was taken on August 26, 1976. Image 289.

Figure 730. Conus tortilis from the Moodys Branch Formation at Town Creek (MGS locality 1) in Jackson, Mississippi, showing pits along spire where shell samples were taken for oxygen isotope analysis. Picture was taken by George Phillips on July 15, 2008. Image 1064b.

The Lutetian Stage of the Eocene is between 47.8 and 41.2 million years old and is the age of area French limestone used in the construction of many buildings in Paris. It is also the age of nummulitid limestone used in the pyramids of Egypt. An equivalent limestone from western Turkey is sold as stone tile under the name Honed Seagrass Limestone. In the late Lutetian Stage, the Cook Mountain Limestone (**Figure 728**) was deposited across eastern Louisiana, Mississippi, and into Alabama.

A fossil *Nypa* fruit from the Cook Mountain Formation in Newton County indicates that the Middle Eocene Sea in central Mississippi (**Figure 729**) had a mangrove swamp along its shoreline. Nypa is known as the mangrove palm and is associated with mangroves in tropical and subtropical shorelines.

Figure 729. Internal mold of a fossilized *Nypa* nut from the Cook Mountain Formation at Newton, Mississippi. The gap between the mold and the surrounding matrix was once occupied by the shell of the nut, which when originally found had a coconut-like husk. This specimen is now on display in the Stories in Stone exhibit at the Mississippi Museum of Natural Science. The picture was taken around January 1999; scale in centimeters. Image 2241.

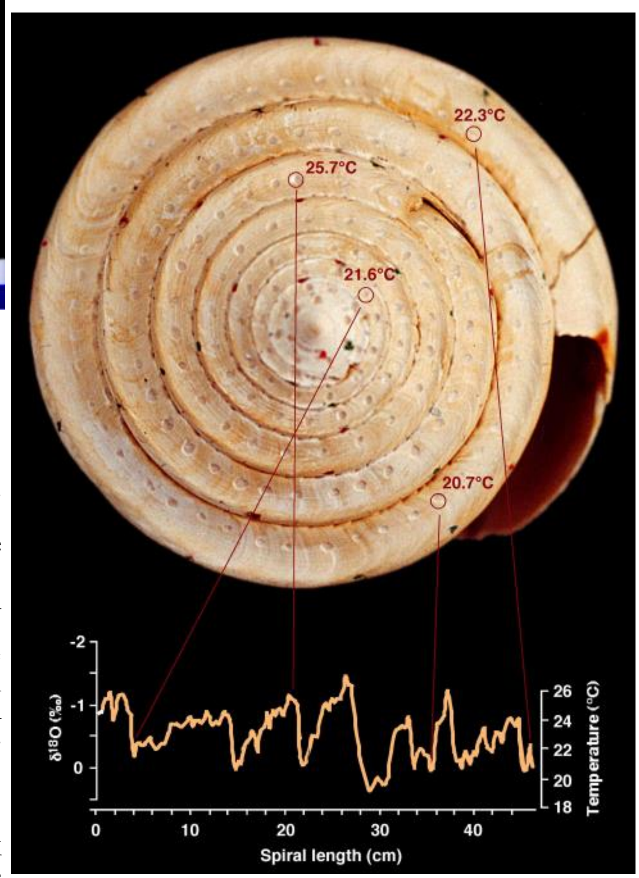


Figure 731. Oxygen isotope/sea-water temperature sample sites along the spire of a 7.5-year-old specimen of Conus tortilis from the Moodys Branch Formation at Town Creek in Jackson, Mississippi. Picture from Takuro Kobashi (published in Kobashi et al., 2001, Geology). Image 1115.

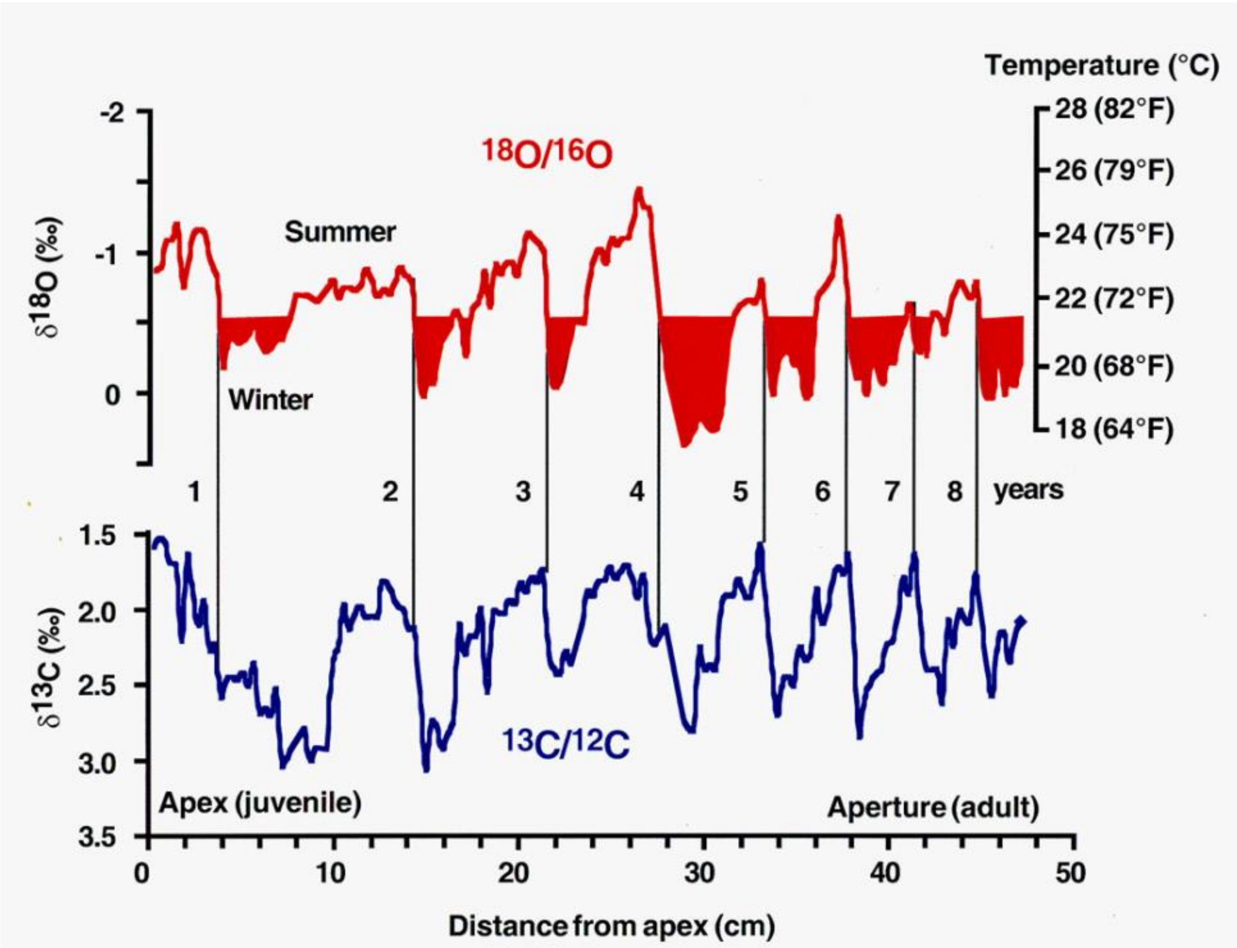


Figure 732. Oxygen isotope and carbon isotope ratios for a *Conus* shell from the Moodys Branch Formation at Town Creek in Jackson, Mississippi, showing an eight-year record of shell growth and ancient seawater seasonal temperatures. Figure by Kosbashi and Grossman. Image 1195.

Late Eocene Bartonian Greenhouse Earth. *From Greenhouse to Icehouse, The Marine Eocene-Oligocene Transition*, (Prothero et al., 2003), by Columbia University Press, used the term Greenhouse to describe the Eocene Earth. The Late Eocene Bartonian Stage, which followed the Lutetian, includes the Auversian Regional Stage of the French Paris Basin and the Moodys Branch Formation of Louisiana, Mississippi, and Alabama. Fossil mollusks from the Paris Basin Auversian and Mississippi's Moodys Branch formation have many closely related species. Kobashi and Grossman (2003) drilled cones shells from the Moodys Branch Formation at Jackson, Mississippi, for oxygen isotopes and reconstructed the seasonality of Late Eocene seawater (**Figure 730-732**). This seasonality showed the winter-time temperature of the seawater to be warmer than that of our Gulf Coast today, and thus more tropical.

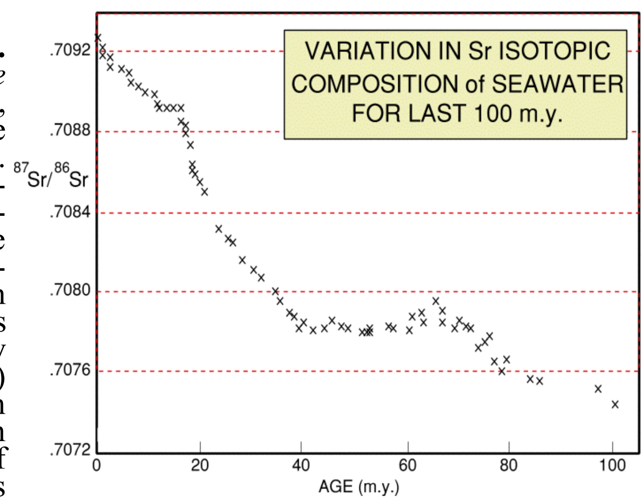


Figure 733. Seawater strontium isotopic composition of seawater over the last 100 million years after Richter et al., 1992. Image 2630.

Seawater $^{87}Sr/^{86}Sr$ Isotopic Composition. Strontium-87 is derived from the radioactive decay of Rubidium-87, thus the $^{87}Sr/^{86}Sr$ ratio must increase with time. However, the Earth's mantle is low in Rb relative to Sr, while crustal rocks such as granites and shales are rich in Rb. So if seawater interacts chemically with crustal rocks, the $^{87}Sr/^{86}Sr$ ratio increases, while if seawater interacts predominantly with mantle rocks (i.e. submarine volcanic activity) the ratio decreases. **Figure 733** gives the global $^{87}Sr/^{86}Sr$ ratio of seawater over the last 100 million years.

Enhanced erosion of high $^{87}Sr/^{86}Sr$ continental material due to continental collisions and mountain building will drive up the seawater $^{87}Sr/^{86}Sr$ ratio. Weathering of granitic material such as feldspars and micas release radiogenic Sr as they break-down to clays. This strontium is very soluble in water and is flushed to the sea by rivers draining mountainous terrain, such as the Alps, Himalayas, and Andes. The steady increase in the $^{87}Sr/^{86}Sr$ ratio from 38 million years ago to the present is a result of the continental collision between India and Asia beginning at a time that coincides with the age of the Moodys Branch Formation. The $^{87}Sr/^{86}Sr$ ratio composition of seawater in **Figure 734** is based on samples from fossil molluscan shells in Mississippi's Paleogene section, using primarily the calcite shells of oysters and pectins to avoid diagenetic changes in composition. Both graphs show a rise in ratio values beginning at 38 million years ago. Thus a collision of continents on one side of the world is

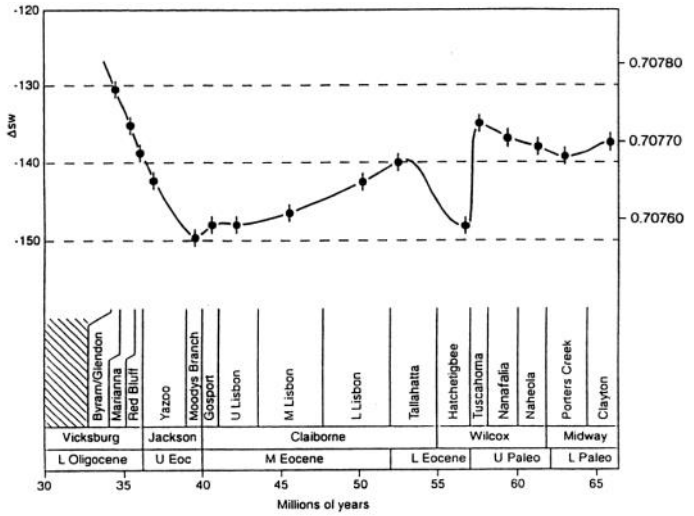


Figure 734. Strontium isotope ratios for the Gulf Coastal Plain Paleogene section as determined from the calcitic shells of oysters and pectens by Denison et al. (1993). Sea water strontium isotope ratios are low in the Moodys Branch Formation and increase linearly to the present day ratio. The low value for the Early Eocene Hatchetigbee Formation is anomalous due to the local paleoenvironment. The Moodys Branch Formation is the low point for the Cenozoic record. Image 1309.

Figure 735. Mint Spring Formation at Mint Spring Bayou in the Vicksburg National Cemetery; left to right are Laura Stafford, Bruce Wilkinson, and Linda Ivany. The Mint Spring Formation is in the undercut below the lower ledge of the Glendon Limestone and softer underlying Marianna limestone. Picture taken on May 16, 2002. Image 48.

Figure 736. Contact of the light-gray Shubuta Clay and dark-gray Red Bluff Formation at MGS locality 34 on the Chickasawhay River in Wayne County. Picture was taken on September 7, 1978. Image 195.

Figure 737. Contact of the Shubuta Clay and overlying Red Bluff Formation at MGS locality 34 on the Chickasawhay River in Wayne County. Picture (Kodachrome slide 51-19; Image 194) taken on September 6, 1978. Image 194.

Figure 738. Beverly Schabilion and Jim Pitts beside a petrified log from the Forest Hill Formation in the badlands of the Mississippi Petrified Forest at Flora, Mississippi. Picture (slide from the Schabilion family; Image 1695) taken in November of 1965 by G. Holly. Image 780.

recorded in fossil seashells in Mississippi on the other side.

The weathering of crustal rock in the uplifted Himalayas also sequestered large amounts of atmospheric carbon dioxide and contributed to the switch from a greenhouse earth to an icehouse earth, with the formation of ice sheets in Antarctica. One indicator of a cooling climate is the appearance of oak pollen in the upper Yazoo Clay.

Oligocene Icehouse Earth. Linda Ivany et al. (2000) studied the isotope records of otoliths from the cusk eel *Ariosoma* from the Eocene and Oligocene of Mississippi and found that the surface water winter temperatures were colder in the Oligocene. One specimen from the Mint Springs type locality (**Figure 735**) had a seasonal range of 9.3°C (16.7°F). Ivany et al. (2000) attributed the colder Oligocene winter seawater temperatures to marine extinctions at the Eocene-Oligocene boundary (**figures 736-737**). Dockery (1986) recognized a 96.7 % extinction rate for molluscan species at the Eocene-Oligocene boundary in Mississippi.

The seasonal range of seawater today at Mobile, Alabama, is 28°F from a winter low of 58°F to a summer high of 86°F. Thus, the Oligocene ocean that once existed in Mississippi was more tropical than today, but less topical than that of the Eocene. Kosbashi et al. (2001) in a study of oxygen isotopes in cone shells found that seasonal oxygen isotopes indicated a decrease in surface seawater temperatures from 26-27°C (78.8-80.6°F) in the Eocene to 22-23°C (71.6-73.4°F) in the Oligocene. This trend showed more significant winter cooling (5°C) than summer cooling (3°C).

Mississippi Petrified Forest. Fossil wood in the Early Oligocene Forest Hill Formation contains giant logs (**Figure 738**) of sequoia, maple, fir, and spurge and such trees as *Cupressinoxylon florense* an extinct conifer related to the present day families Podocarpaceae and Cupreassaceae, families living predominantly today in the Southern Hemisphere. According to Schabilion (1996) specimens of fossil wood from the Petrified Forest were sent to Francis M. Hueber, Associate Curator, Division of Invertebrate Paleontology and Paleobotany at the Smithsonian in 1962 for identification. The six specimens sent were determined to be angiosperms that lacked annular rings indicating a uniform climate. In July 1967, Virginia M. Page of the Department of Biological Sciences, Stanford University, California identified a specimen as *Abies* or Fir, a confirmation of earlier work. Other specimens

Figure 740. Petrified palm stump from the lignite bed in the Forest Hill Formation on Cold Creek in the NE/4, Section 25, T. 9 N., R. 4 W., Yazoo County, Mississippi. The stump's exterior is silicified, while the middle is lignitized. Picture was taken on September 9, 2010. Image 1703.

Figure 741. Fossil palm fronds at a fossil leaf locality (MGS locality 172) in a clay pit in the weathered Bucatunna Formation just east of Business Highway 61 and just south of MGS locality 140 in the Byram Formation in northern Vicksburg in Warren County, Mississippi. Picture was taken by Dana Link on March 30, 2008. Image 997.

were members of the spurge family Euphorbiaceae, which lives today in southeast Asia. The petrified logs of the Petrified Forest were of much larger tress than those of living Asian spurge trees. **Figure 740** shows a partially petrified palm stump protruding from a lignite bed in the upper Forest Hill Formation in Yazoo County.

Early Oligocene to Miocene Characterized by Coastal Palms. Fossil palm remains occur in the Glendon Limestone (**Figure 779**) and Bucatunna Formation (**Figure 741**) of the Early Oligocene Vicksburg Group, from

Figure 742. Imprint of a palm trunk in Glendon Limestone from the Marquette Cement Manufacturing Company's quarry at Brandon, Mississippi. Image 2631.

the Catahoula Formation (**figures 742-745**) of Late Oligocene to Miocene age, and from the Hattiesburg Formation (**Figure 746**) of Middle Miocene age. Collectively, these occurrences indicate the existence of a coastal palm forest across central Mississippi during Oligocene and Miocene time.

Figure 743. Left; petrified palm trunk of the species *Palmoxylon lacunosum* (Unger *in* Martius, 1845) from the Catahoula Formation in White Oak Creek in Claiborne County, Mississippi. The trunk is 21.5 inches in diameter at the base, 60 inches long, and weighs 500 pounds. Image 2632.

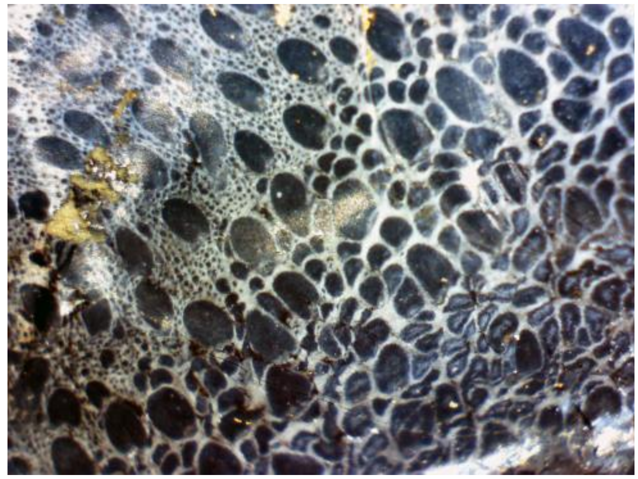


Figure 744. Cross section of *Palmoxylon lacunosum* from a black quartzite bed in the upper Catahoula Formation on the Bayou Pierre at the Copiah/Claiborne County line. Microphotograph was taken by James Starnes September 27, 2013. Image 2633.

Figure 745. Palm fronds from the basal Catahoula Formation at the Jones Branch Locality in Waynesboro, Mississippi. Pictures by James Starnes taken on July 2, 2014. Images 2634.

Figure 746. Palm fronds from the Hattiesburg Formation on the Bowie River at Hattiesburg, Mississippi. Picture taken by James Starnes on November 2, 2014. Image 2635.

Figure 747. James Starnes on clays in the Pliocene Graham Ferry Formation on Saucier Creek in Harrison County near the intersection of highways 49 and 67 where lignitic White Pine wood and a pine cone were found. Picture was taken by Lindsey Stewart on December 10, 2014. Image 2636,

Figure 748. Lignitized White Pine stump and roots in the Graham Ferry Formation on Saucier Creek in Harrison County. Picture was taken by James Starnes on December 10, 2014. Image 2637.

Figure 749. White Pine pinecone from the Graham Ferry Formation on Saucier Creek in Harrison County. Scale in inches. Picture was taken by James Starnes on December 11, 2014. Image 2638.

Pliocene Coastal Pine Forests. Pliocene coastal pine forests of the northern Gulf Coastal Plain consisted of White Pine, a species now found much further north. Stults et al. (2010) reported White Pine *Pinus strobus* in the Citronelle Formation of Alabama. New geologic mapping now places their fossil plant locality in the Pliocene Graham Ferry Formation (Starnes, personal communication). **Figure 747** showing James Starnes standing on a silty clay in the Graham Ferry Formation on Saucier Creek in Harrison County, Mississippi, at a fossil plant locality. **Figure 748** shows a rooted pine stump in the Graham Ferry Formation, and **Figure 749** shows a lignitized White Pine pinecone. Today White Pine occurs at higher latitudes in North America as shown in **Figure 750**. Thus, the Miocene -Pliocene transition in the northern Gulf Coastal Plain is one from palms to pines.

Pleistocene Coastal Spruce Forests. **Figure 751** show the range of spruce, *Populus tremuloides*, in North America. Today Spruce trees are found in northern temperate and boreal regions of the continent. Brown (1938) collected the wood and fruit of northern tree species such as white spruce (including entire cones), larch, and white cedar, in association with a tapir molar and mastodon tusk, in the Pleistocene alluvium of streams in Louisiana. Pollen from sedimentary cores drilled in the Pearl River floodplain in association with the proposed Shoccoe Dam Project revealed a change in forest conditions around 9,300 years ago, when Pleistocene boreal forests of spruce were replaced by oak, hickory, and gum (Dunbar and Coulters, 1988; Albertson and Dunbar, 1992). Davis (1983, p. 179) noted a change in the central Gulf Coastal Plain forests at 10,000 years ago from boreal (i.e. spruce) to deciduous species such as oak, sweet gum, and

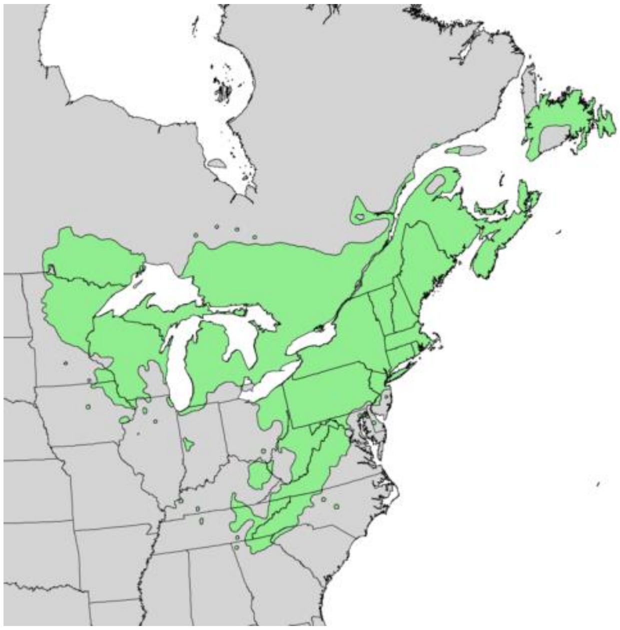


Figure 750. Modern distribution of the Eastern White Pine (*Pinus strobus*) in North America, from Wikipedia. Image 2639.

Figure 751. Modern distribution of Spruce in North America, including Red Spruce (*Picea rubens*), Blue Spruce (*Picea pungens*), Black Spruce (*Picea mariana*) White Spruce (*Picea glauca*), and Sitka Spruce (*Picea sitchensis*), from Wikipedia. Image 2640.

hickory, and at 5,000 years ago from oak– to pine-dominated forests (Dockery and Thompson, 2016).

Holocene Coastal Plain Longleaf Pine and Hardwood Forests. Early European settlers found the coastal plain of the Southeastern United State forested in magnificent columns of longleaf pine with understories so clear of shrubs that a horse could run through the forest at a full gallop (**Figure 753**). B. L.

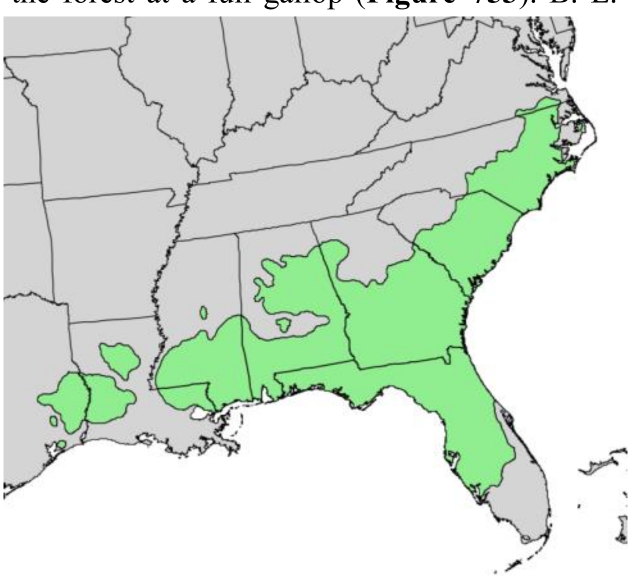


Figure 752. Modern distribution of longleaf pine (*Pinus palustris*) in Southeastern North America, from Wikipedia. Image 2641.

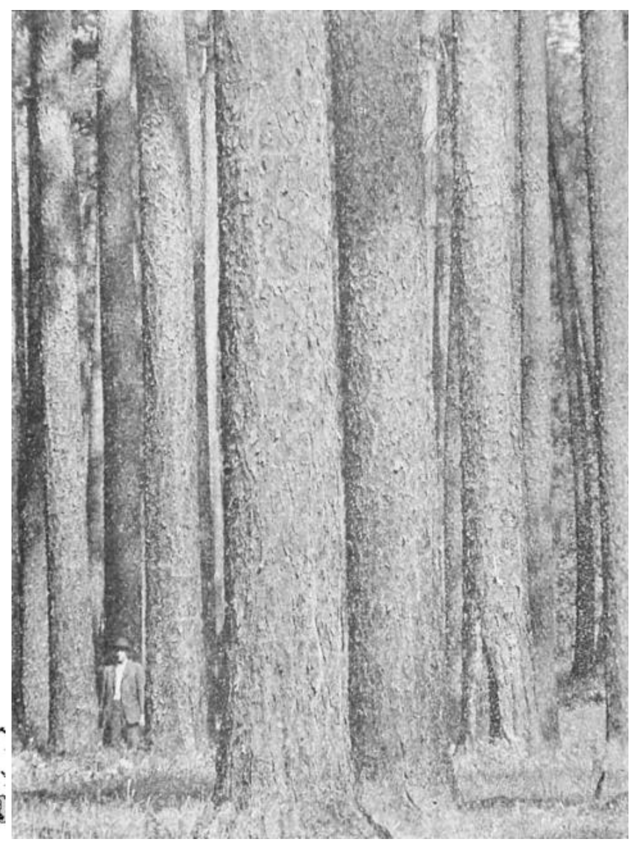


Figure 753. Longleaf Yellow Pine. From Mississippi Geological Survey Bulletin 8, 1911, A Preliminary Study of Soils of Mississippi, by E. N. Lowe, p. 151. Image 2642.

C. Wailes poetically described travel through such a forest in southwestern Mississippi in an address to Jefferson College dated October 1844 as follows:

"Extending northward into the interior above the former limits of West Florida the surface becomes higher, more undulating and occasionally quite broken. Here the timber becomes larger, and over considerable tracts the long leaf pine usurps almost exclusive dominion. Straight, massive and branchless to near the top, which seems to spread a canopy in the blue ether of the skies, there is a grandeur and majesty in these trees peculiar to such forests alone. Far removed from human habitation, on every side an interminable vista of towering columns is presented broken by no moving object or sign of living thing, whilst the gentle breathing of the winds, through the pinated foliage of the lofty canopy, comes down upon the ear like the distant moaning of a gathering storm filling the lonely traveler with a sense of solitude almost oppressive."

Recent Tropical Plants on the Mississippi Gulf Coast. If the climate reversed to what it was before the Pleistocene Ice Age spruce forest and before the Pliocene white pine forest, Mississippi would have a palm and mangrove forest coastline. The following is from the MDEQ's July 2012 issue of Environmental News, p. 11-12:

Mississippi's geologic history helps put a recent news story into perspective. Ben Raines reported (July 9, 2012, on AL.com) the recent appearance of black mangrove trees at the mouth of the big lagoon on Horn Island, Mississippi, the most northerly occurrence of mangroves in the Gulf of Mexico. He titled the report, "Mangrove trees showing up on Horn Island may indicate climate change." The Horn Island mangroves include one bush-sized tree and three smaller ones. These trees are many miles north of the closest group of mangroves, which inhabit the Chandeleur Islands off Louisiana. The occurrence of mangroves in the Chandeleurs is also a recent phenomenon attributed to recent warm winters. There is some concern that the mangroves might interfere with the growth of spartina and juncus marsh grasses on Horn Island, but mangroves have colonized the area before only to be wiped out in particularly cold winters. The present Horn Island mangroves have also died back a couple of times only to rebound, the cold weather killing the tops but not the roots. **Figure 754**, at left, shows scientists from the Dauphin Island Sea Lab, the U.S. Fish & Wildlife Service, and the National Park Service studying a black mangrove bush (flowering in the foreground) on Horn Island, and, at right, mangroves along the tropical shoreline of Puerto Rico.

In the Middle Eocene Epoch some 40 million years ago, Mississippi's climate was much warmer than it is today, and most of the state was covered by a tropical sea. Along the sea margin in the northeastern part of the state was a mangrove-forested shoreline. One interesting inhabitant of these mangrove swamps was a palm tree of the genus *Nypa*, the only palm adapted to life in a mangrove forest. Today *Nypa* palms are native to the tropical coastlines and estuaries of the Indian and Pacific Oceans, from Bangladesh to the Pacific Islands. This palm has a sugar-rich sap that can produce 6,480-15,600 liters per hectare of fuel (ethanol or butanol) per year, as compared to only 5,000-8,000 liters for sugarcane. **Figure 729** (shown in the Middle Eocene Optimum section) is a fossil *Nypa* nut found by James K. Smith in the Cook Mountain Formation at Newton, Mississippi, during the con-

Figure 754. At left in foreground, black mangrove tree with blossoms at the mouth of the big lagoon on Horn Island, Mississippi (from Ben Raines, Al.com, published July 9, 2012); at right, a mangrove swamp on the Caribbean Coast of Puerto Rico (picture taken in February of 1977). Image 2240.

Figure 755. At left, *Nypa fruticans* (*Nypa* palms) growing in a mangrove swamp in Bohol, Philippines; at right, Nypa fruticans nut. Image 2242.

struction of Interstate 20. **Figure 755**, at left, shows the modern *Nypa* palm species *Nypa fruticans* growing in a mangrove swamp, and, at right, a *Nypa* palm nut. Fossil *Nypa* nuts are also known from the Middle Eocene sand beds of Branksome, England, and in the London Clay on the Isle of Sheppey, Kent, indicating a much warmer climate in the British Isles at that time.

The Possible Rapidity of Climate Change Under Natural Conditions. The following is from MDEQ's December 2009 issue of Environmental News, pages 9-13:

During the present ice age of the last 2 million years, in a time called the Pleistocene Epoch, glaciers have advanced and retreated over 20 times, often blanketing much of North America in ice. According to NOVA's special *The Big Chill* by Kirk Maasch, "Our climate today is actually a warm interval between these many periods of glaciation. The most recent period of glaciation, which many people think of as the 'Ice Age,' was at its height approximately 20,000 years ago." That ice age lasted 100,000 years and covered Canada and the north United States in thick sheets of ice.

During the Pleistocene, glacial periods were long lived while interglacial periods were relatively short, lasting on the average only about 12 thousand years. The present interglacial period, called the Holocene, has already lasted over 11 thousand years but would have been on the order of 15 thousand years long if not for a climatic glitch 12,800 years ago that sent the planet back into a thirteen-hundred-year-long ice age. This ice age is known as the Younger Dryas (from 12,800 to 11,500 years ago). At about this time, central Mississippi was covered by a boreal forest (like that of

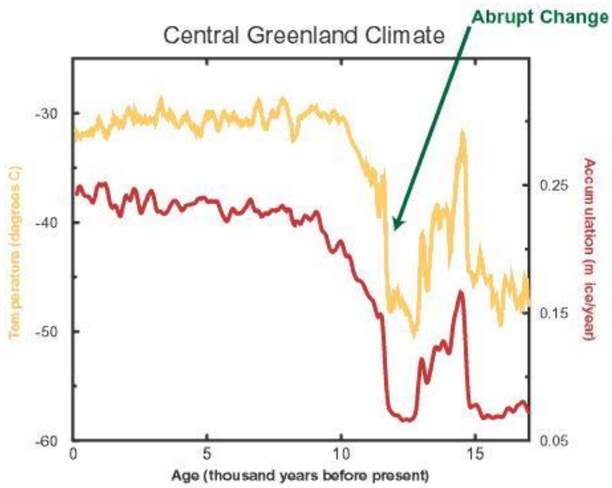


Figure 756. The yellow curve gives the temperature in degrees C for central Greenland over the last 18,000 years. The red curve gives the accumulation of ice in meters per year over the same time period. YD designates the Younger Dryas glacial period. This diagram was published online by the Lamont-Doherty Earth Observatory. Image 2643.

northern Minnesota), as is evidenced by spruce pollen found in cores from the Pearl River flood plain in Leake County.

One alarming thing about the climate change 12,800 years ago is that it occurred over a period of ten years or less (**Figure 756**). This rapid climate change was the inspiration for Kim Stanley Robinson' novel *Fifty Degrees Below*, for Art Bell and Whitley Strieber's book *The Coming Global Superstorm*, for John Christopher's novel *The World in Winter*, and for the 2004 apocalyptic science-fiction film *The Day After Tomorrow*. If the initial Youger Dryas climate event happened again today, we would be making international

Figure 757. Lois Nettleton as Norma in "The Midnight Sun," from the Wikipedia. Image 2644.

Figure 758. Marlene's husband David and children standing of the frozen surface of Lake Ponchartrain on December 25, 1989. Picture taken by Marlene. Image 2645.

plans to curb global warming one year, probably blame La Niña for the following cold year or two, and within just a few years would be facing an ice age we would be powerless to stop. An apocalyptic scenario for such an event would be the forced migration of hundreds of millions of people in North America, Europe, and Asia, who would have to abandon their homes and cities and move south. Stay-home ice-age-deniers would become snowbound and perish. The entire population of Great Britain might have to move, but where? Hopefully, the extra CO_2 we've added to the atmosphere will forestall a sudden ice-age appearance, but the unpredictability of what's to come, whether too hot or too cold, brings to mind an episode of the *Twilight Zone* entitled *The Midnight Sun*, which originally aired on television on November 17, 1961.

In *The Midnight Sun*, Norma, an artist (**Figure 757**), and her landlord Mrs. Bronson are the only people left in their New York City apartment building. All the other tenants have moved north trying to escape the heat; the city streets are largely disserted. Rod Serling's opening narration explains that the earth has suddenly changed its elliptical orbit for one that is spiraling into the sun. The earth is doomed and people have been handed a death sentence. Mrs. Bronson is disturbed by Norma's paintings of the hot sun against the city skyline and requests that she paint a waterfall. The next day, Norma presents her waterfall picture to Mrs. Bronson, who hallucinates that the scene is real before she collapses and dies in the heat. Norma is distraught over the death of her friend but then is alarmed for herself as she sees the mercury in the thermometer top out and then explode. Norma screams when she sees the oils of her waterfall painting melt and run down the canvas; she then falls unconscious to the floor. In the final scene, Mrs. Bronson and a doctor are caring for a feverishly sick Norma, who is waking from her illness in her apartment-room bed. Outside the apartment is bitter cold, and the thermometer registers no heat at all. The doctor tells Mrs. Bronson he will not be back to check on Norma because he is moving south. The truth is--the earth is a doomed planet spiraling away from the sun into the darkness of space. Norma tells Mrs. Bronson her terrible dream of a sun so hot that it was even bright at midnight. She then says, "Isn't it wonderful to have darkness, and coolness?" In a dreadful voice, Mrs. Bronson replies, "Yes, my dear, it's….wonderful."

Weather, Seasonality, and Climate. The difference between weather, seasonality, and climate is: weather is what we have today; seasonality is a the measure of weather over a year, and climate is the average seasonality over a long period of time. Even so, climate gains in the spread of tropical species can be set back a hundred years by one cold weather event. Many generations of New Orleanians have enjoyed the city's majestic palms. The cold weather of Christmas 1989 killed off the tall stately palms in the median of St. Charles Street and elsewhere in New Orleans, permanently changing the look of the city; these were later replaced with smaller, more cold-tolerant palm species.

On December 23 the high in New Orleans was 26° F and the low was 12° F; the city spent 81 or 82 hours, beginning on December 22 and ending on December 25, below freezing. Lake Pontchartrain was iced over like Lake Michigan (**Figure 758**). The freeze killed every golden rain tree (*Koelreuteria bipnnata*) and camphor tree (*Cinnamomum camphora*) in the city and hundreds of palm trees. In June of 1990 there were so many dead trees that the

Figure 759. The tall palm tree in the median of St. Charles Street in New Orleans, to the left of the trolley, is dwarfed by the one behind it, which towers over the live oak trees. These, and other palm trees in New Orleans, were killed by record cold weather in 1989. Picture was taken in the winter of 1976. Image 1325.

city almost looked like winter (Gill, 2014). Doughty et al. (1994) surveyed 9,039 palms in the New Orleans area from August 16 through October 30, 1990, comprising 14 genera and 21 species for freeze damage. Around one third of these palms were found to be in fair or poor condition, and, because of their unsightly appearance, many were later removed by the city. Lost to the frost and city removal were the large palms on St. Charles Avenue shown in **Figure 759**.

The 1989 freeze was also one of the longest and most widespread in Florida, with freezing temperatures as far south as Miami. The freeze, snow, and ice from December 23-25 closed interstate highways and airports in central Florida and killed all the coconut palms north of southern Florida.

Figure 760. David, Fluffy, and Gwin Dockery on Manila Drive as viewed looking north in Jackson, Mississippi, on January 10, 1962. Image 1221.

A Jacksonian's Lifetime Low Temperature (Dockery). In Jackson, Mississippi, after several inches of snowfall on Tuesday January 9, 1962 (**Figure 760**), the low temperature on the morning of January 10 was 4° F. Neighborhood children could walk across frozen ponds. Such icy activities continued as the low on January 11 was 1° F and on the 12th was –1° F. On January 13, the morning low warmed up to 9° F. According to the April 1962 issue of the U.S. Weather Bureau's journal *Weatherwise* (page 84), "four successive anticyclones, each of greater magnitude, poured icy blasts to the semi-tropical extremities of the country" in January of 1962 and "won a unique place in the weather annals of the country."

Climate and Space Weather. Weather emergencies and recent major water main breaks for the City of Jackson have followed the 11-year periods between peak activity in sunspot cycles. The sun is 0.1% dimmer during sunspot minima. **Figure 76**1 is a graph of sunspot cycles 22-24, with minima marked (X) in February 1996, January 2010, and January 2018. **Figure 762** shows frozen lakes at Mossy Grove north of Clinton, Mississippi, in northwestern Hinds County (lakes that rarely freeze over). Major breaks in Jackson, Mississippi, water mains occurred in January of 2010 and 2018.

The study and recording of sunspots dates to the early seventeenth century. According to solar physicist Solanki of the Max Planck Institute in Katlenburg-Lindau, Germany, the last 70 year has seen the most intense period of sunspot activity in for the past 8,000 years (Reimer, 2004; Solanki et al., 2004). Solanki et al. (2004) recognized that solar variability has contributed to the unusual climate change of the twentieth century but that it was unlikely to have been the dominant cause of strong global warming over the past three decades. From 1985 to the present, this activity has been on the decline as show in **Figure 761**.

Sunspots boost the solar wind and open magnetic flux—the magnetic field that extends into the inter-planetary space. This magnetic field deflects charged particles such as cosmic rays so that fewer of them enter the Earth's atmosphere. Cosmic rays create carbon 14 and beryllium 10 in the atmosphere. Carbon 14 is absorb as carbon dioxide in tree rings, thus preserving a record of sunspot activity, extending through a 11,000-year dendrochronology record as published by Solanki et al. (2004).

In a period between 1650 and 1700, astronomers saw virtually no sunspots in an

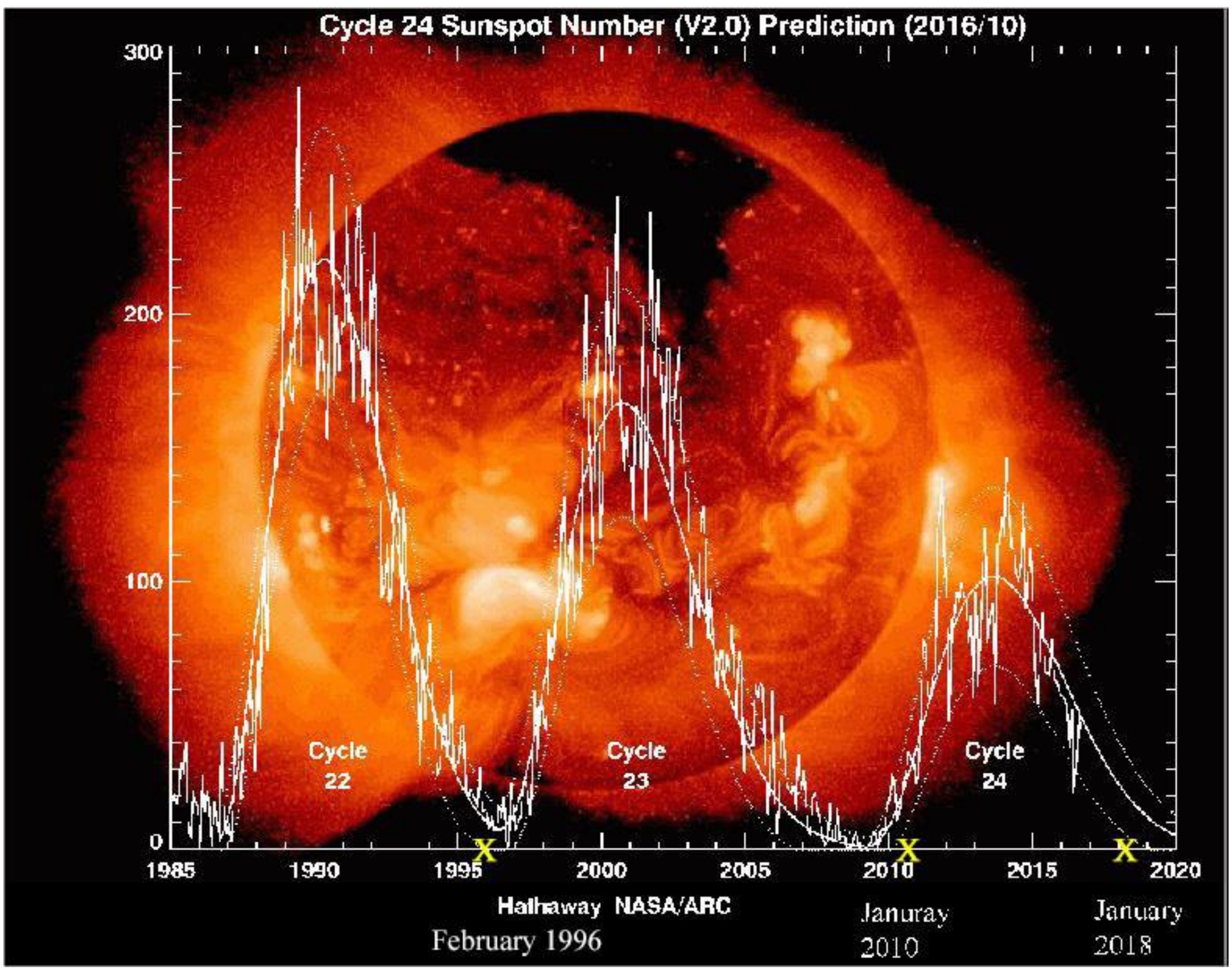


Figure 761. Sunspot cycles 22 to 24 from January 1985 to January 2018. Yellow Xs are extreme cold weather events for the Jackson, Mississippi, area. Figure from David Hathaway, a solar physicist from NASA's Marshall Space Fight Centre in Huntsville, Alabama.

Figure 762. Frozen upper (left) and lower (right) lakes at Mossy Grove in northwestern Hinds County north of Clinton, Mississippi, as photographed on February 5, 1996 (top), January 9, 2010 (middle), and January 17, 2018 (bottom pair). At bottom right is the frozen surface of the lower lake as photographed with the camera on the ice on January 18, 2018.

event known as the Maunder Minimum. This minimum coincided with the coldest part of a period called the Little Ice Age, an indication that the sun's activity significantly affects our climate.

Air, Water, and Land. Clean air, water, and land are our most important strategic resources and are the emblems that make up the three rings of the Mississippi Department of Environmental Quality logo (**Figure 763**), which has primacy (oversight, and enforcement responsibility for the public) in these areas. Polluted air is unsafe for everyone, but can be critical to infants, the elderly, and those lung diseases such as asthma and chronic lung disease (COPD). According to Chelsea Harvey (2016) of *The Washington Post*, the cost of air pollution in the U.S. was a "staggering" $131 billion in damages for the year 2011. But the damage caused in 2011 was an improvement over 2002, in which damages totaled $175 billion. The bulk of this cost is related to impacts on public health. In China, the cost of air pollution is estimated to be 6.5% of the country's $11-trillion-plus gross domestic product. The cost estimate is based on lost productivity, as factories are shut down on bad air days, and sick days and hospital visits. More than 1.6 million people die in China per year from breathing toxic air. Air pollution has contaminated some 20% of country's soil. China's largest rice-growing province, Hunan, has soil mixed with heavy metals from factories, tainting the country's food supply.

Figure 763. Logo of the Mississippi Department of Environmental Quality with emblems for air, water, and land. Image 2646.

Clean Freshwater. The cost of freshwater pollution in the U.S. to government agencies, drinking water facilities, and individual Americans is calculated to be at least $4.3 billion a year. Much of the cost is from pollution by phosphorus and nitrogen from nonpoint sources such as agricultural fertilizers on row crops (Kansas State Univeristy, 2008). These elements accumulate in ponds, stream, and rivers, creating algal blooms, and eventually empty in the ocean, where algal blooms can create dead zones on the seafloor. In August 2, 2014, Toledo, Ohio's water supply from Lake Erie was poisoned by high levels of algal cyanotoxins, toxins so potent that the military has considered their potential to be weaponized. Five hundred thousand residents in and around Toledo were without safe drinking water. The dangerous toxin in the Lake Erie blue-green algal blooms was microcytin, a toxin that tragets the liver where it accumulates and clogs. Cows, horses, and dogs died from drinking the lake waters (Frankel, 2014). Toledo's "Do not drink the water" advisory was lifted on August 5, 2014.

According to the Pacific Institute *World Water Day*, 2010, the UN estimates the amount of annual waste water production worldwide at 1,500 km^3, six times more than exists in all the world's rivers. Some 2.5 billion people live without improved sanitation. Infectious waterborne diseases are the number one killer of children under the age of five years old, and more people die from unsafe water than from all forms of violence including war. Unsafe water results in 2.2 million deaths each year. In India alone, diarrhea is the single largest cause of ill health and death among children, killing nearly half a million each year.

Following the Haiti earthquake near Port-au-Prince in January 12, 2010, killing 100,000 to about 160,000 people, the United Nations (UN) and Haitian authorities took responsibility on January 22 to maintain law and order. In October 2010, a cholera outbreak began, which killed 8,231 Haitians and hospitalized 531,000 more (5% of the population) by August of 2013. The outbreak is widely attributed to sewage from UN peacekeeping troops from Nepal, which contaminated a river tributary next to their base. Dr. Paul S. Keim, a microbial geneticist determined that the Haitian and Nepalese cholera strains were identical (Sontag, 2012). Before this, cholera had never been recorded in Haiti. Humanitarian effort had to be diverted from earthquake recovery to a response to the epidemic. Six years after the fact, the UN admitted its role in the Haiti cholera outbreak (Domonoske, 2016).

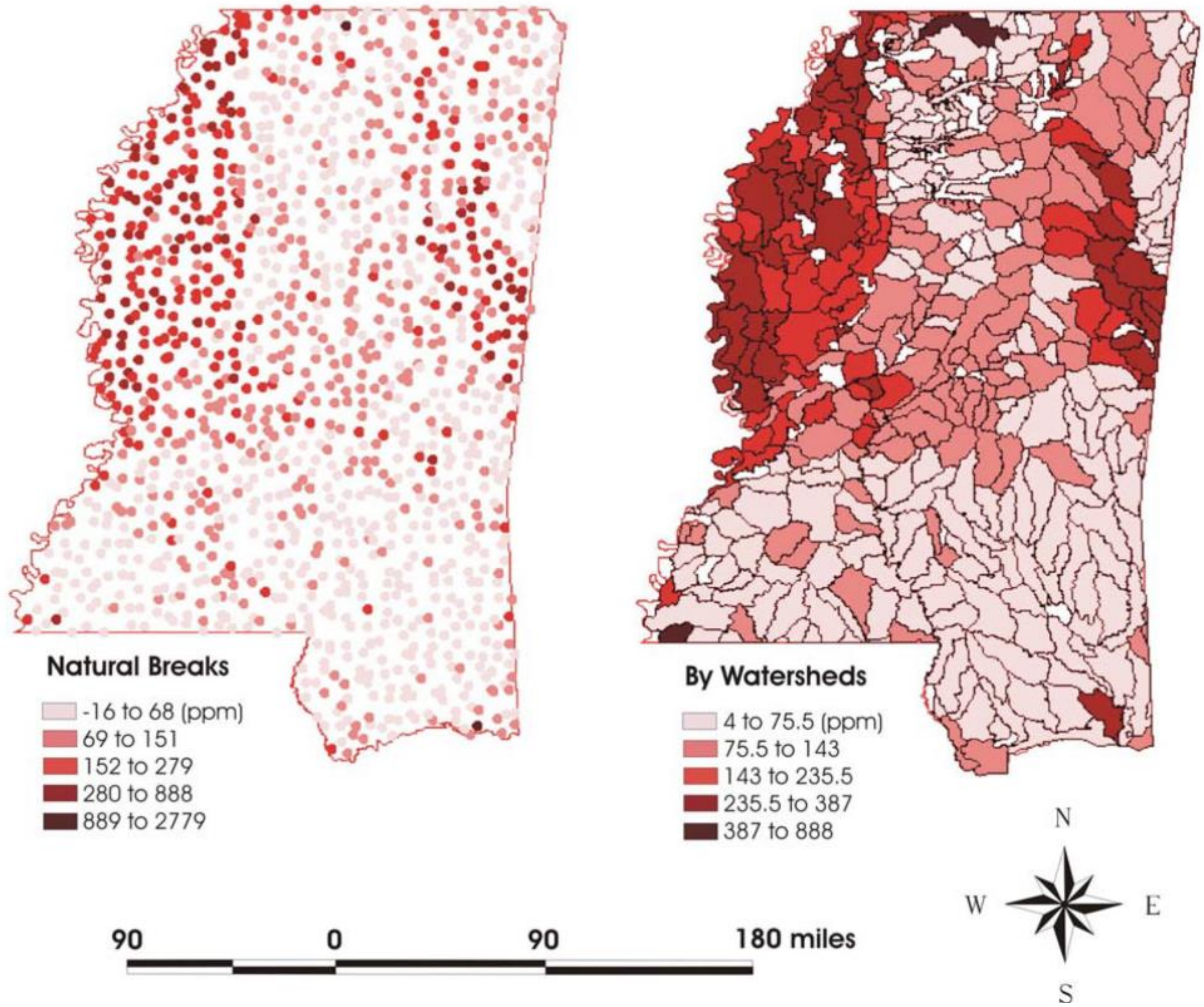


Figure 764. Mississippi toxic elements sum maps for arsenic (As), Selenium (Se), copper (Cu), lead (Pb) and zinc (Zn), from Thompson, 2005. Image 2647.

Clean Land/Soil. A earlier chapter, Chapter 10 on *Geology and Public Health*, includes sections on the proper disposal of household waste, and construction debris, and hazardous waste, and the siting of such landfills. It also showed soil contamination at Superfund and Brownfield sites. Chapter 1 on *Physiography, Ecoregions, and Surface Geology* gives a map on the distribution of the toxic metal arsenic in Mississippi soils. **Figure 764** is a toxic element sum map for arsenic, selenium, copper, lead, and zinc. These metals generally follow agricultural belts in the state, with a few high readings along the Mississippi coast.

Chapter 13 on **Salt Domes** details the nuclear tests in Tatum Salt Dome in Lamar County and the selection of Richton Salt Dome in Perry County as a candidate for a national nuclear waste repository. The Mississippi Emergency Management Agency Office of Radiological Preparedness is in charge of coordination preparedness efforts related to a nuclear or radiological emergency in Mississippi. The agency's Emergency Worker Handbook for 2016, states that, "No deaths or serious injuries have been recorded during 50 years of nuclear power plant production in the United States due to exposure to radiation. This includes the country's only commercial nuclear accident at Three Mile Island."

Figure 765 is from the United States Nuclear Regulatory Commission environmental impact statement published in November 2014 regarding the Grand Gulf Nuclear Station, Unit 1, which had the most powerful nuclear reactor in the United States. It shows areas within six miles and 50 miles of the Grand

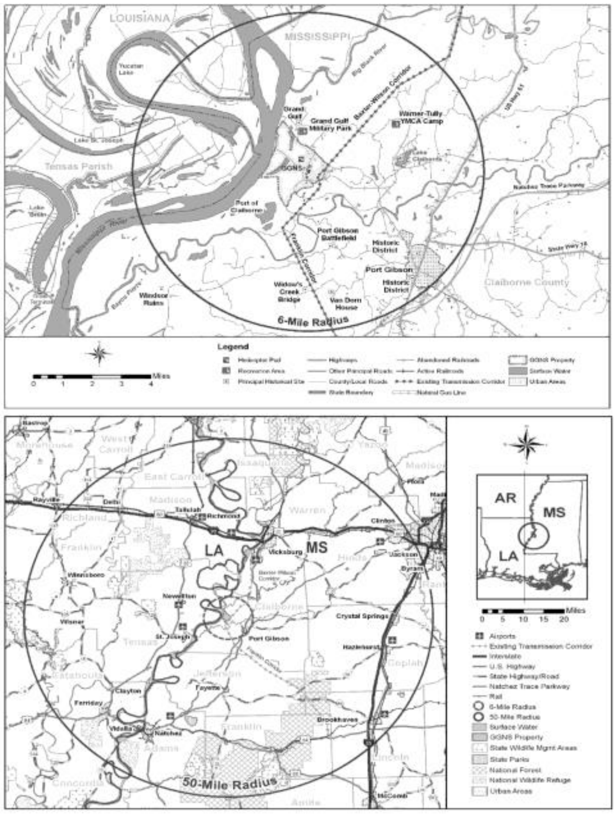


Figure 765. Six mile (30 km) radius circle (top), and fifty mile radius circle (bottom) around the Grand Gulf Nuclear Station, from the U. S. NRC, Generic Environmental Impact Statement of License Renewal of Nuclear Plants. Supplement 50. Regarding Grand Gulf Nuclear Station, Unit 1.

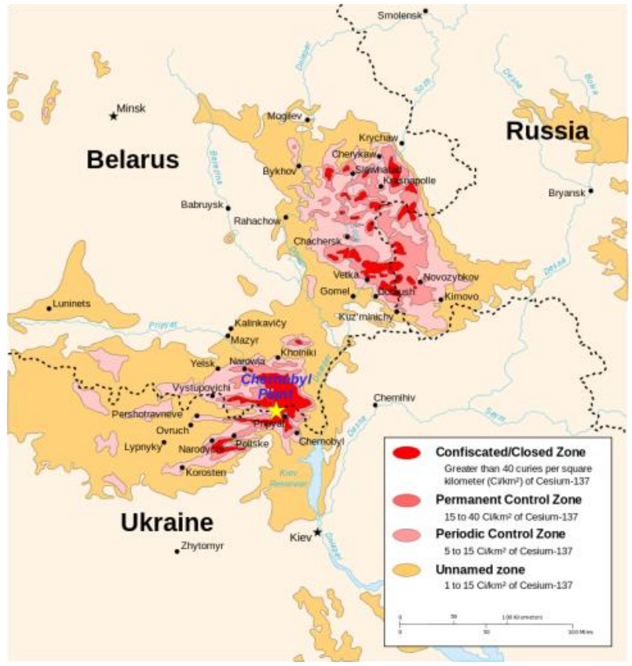


Figure 766. Exclusion zone for the Chernobyl nuclear accident based on the concentration of the radioisotope Cesium-137,from Wikipedia. Image 2648.

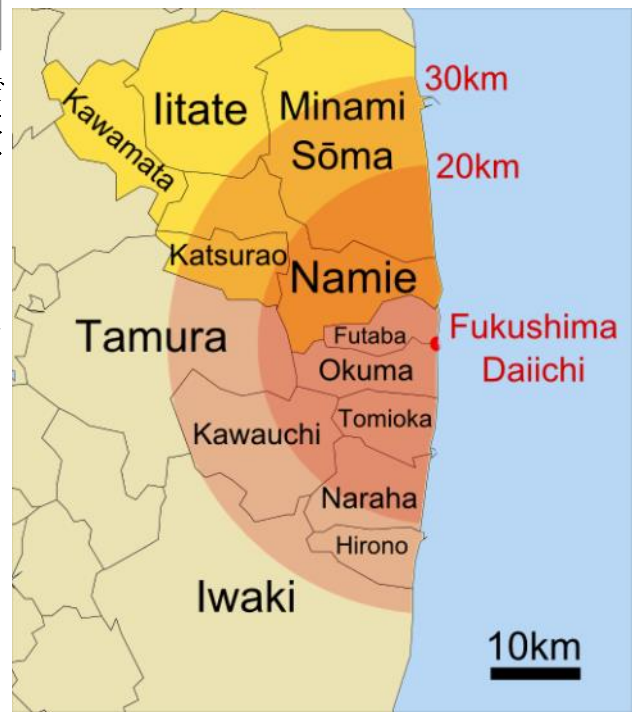


Figure 767. Japnense towns, villages, and cities in and around the Daiichi nuclear plant exclusion zone. The 20 km and 30 km areas were given evacuation and shelter in place orders. Additional districts under evacuation orders are highlighted. From Wikipedia. Image 2649.

Gulf Nuclear Plant, which could be impacted by an accidental release of radiation. The Nuclear Regulatory Commission defines two emergency planning zones around such nuclear plants, a plume exposure pathway zone of 10 miles (16 km) and an ingestion pathway zone of 50 miles (80km) where soil and food could be contaminated.

Though there have been no serious injuries in this country due exposure to radiation from a nuclear power plant accident, there were two notable nuclear plant disasters at Chernobyl in Ukraine and Fukushima Daiichi in Japan. These disasters have rendered large tracts of land inhabitable and a haunt of radioactive wild animals. The Chernobyl exclusion zone covers parts of three countries (**Figure 766**). The Daiichi exclusion zone includes several provinces in Japan with the eastern half of the 30 km zone extending into the Pacific Ocean (**Figure 767**).

Mississippi's Badlands. Poor agricultural practices in Mississippi in the 19th and early 20th centuries depleted the state's soils, caused significant erosion, filled once navigable rives with silt and tree debris rendering them unnavigable, and created badlands. Such

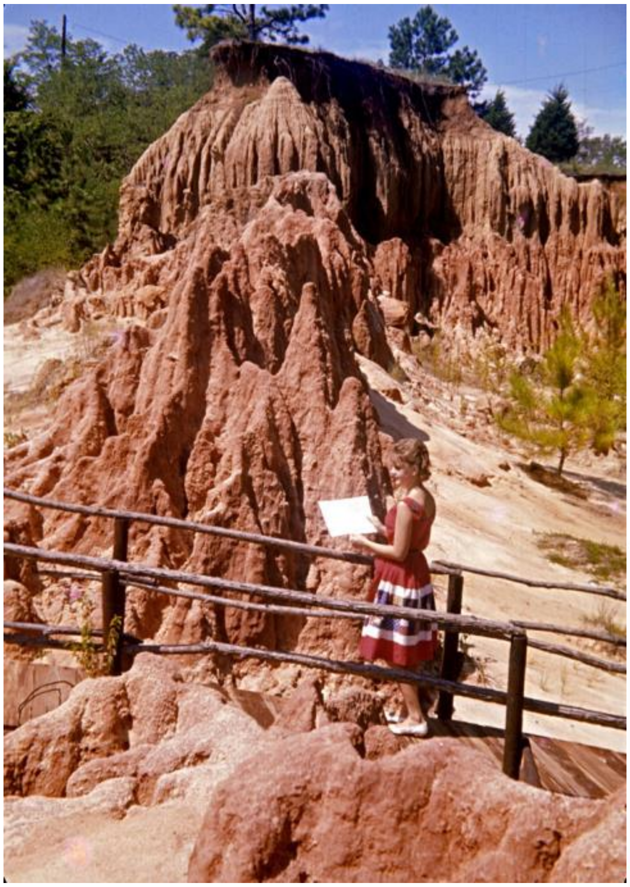


Figure 768. Candace Schabilion on a nature trail in the badlands of the Mississippi Petrified Forest at Flora, Mississippi. The old land surface and soil horizon can be seen on the butte in the background. Below is loess and then pinnacles in the Forest Hill Formation with a petrified log above Candace's head. Picture (slide; Image 1694) taken in the summer of 1963. Image 1963.

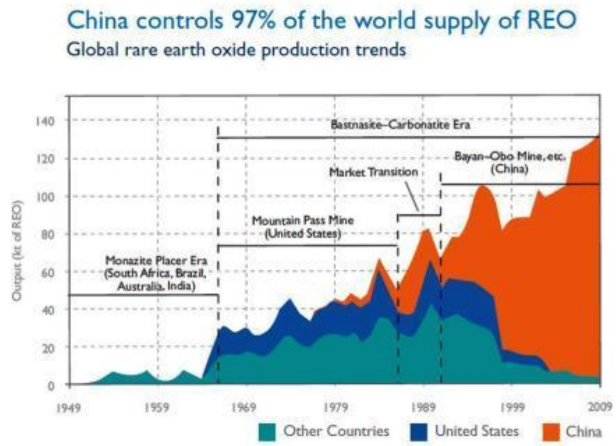


Figure 769. Major suppliers of rare earth elements from 1949 to 2009. Image 2651.

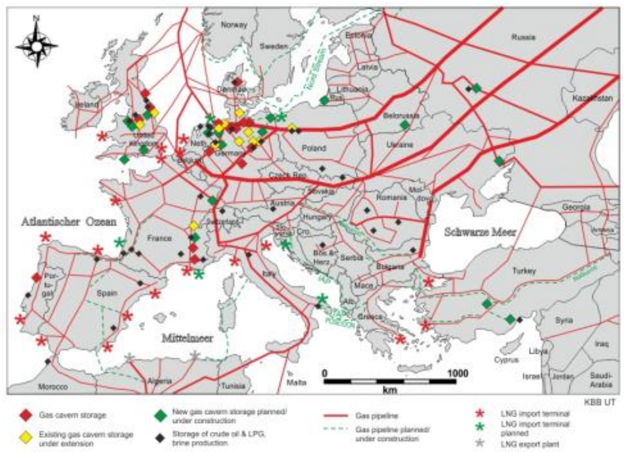


Figure 770. Natural gas pipe lines and storage facilities in Europe. Image 2652.

practices have rendered once productive farmland in places like Rocky Springs on the Natchez Trace to a steep ravine-filled forest land and created badlands at the Mississippi Petrified Forest (**Figure 768**). On April 27, 1935, the U.S. Congress passed Public Law 74 -46 establishing the Soil Conservation Service (SCS) as a permanent agency of the U.S. Department of Agriculture. In 1994, the agency's name was changed to the Natural Resources Conservation Service (NRCS) to reflect a broader scope of activities.

Mississippi has made significant contributions to the field of soil science. The Mississippi Geological Survey was established by the state legislature in 1850 because planters saw the connection between soils and bedrock geology. The state's first geology book in 1854 by planter B. L. C. Wailes was entitled *Report on the Agriculture and Geology of Mississippi* (371 pages). The third such book by Eugene Hilgard (1860) was entitled *Report on the Geology and Agriculture of the State of Mississippi* (391 pages). Hilgard was Mississippi's State Geologist from 1858-1866 and 1870-1872. From 1875 to 1904 Hilgard was Professor of Agricultural Chemistry at the University of California at Berkeley and Director of the State Agricultural Experiment Station. He is widely known today as the "Father of Soil Science."

Strategic Mineral Resources. Mineral resources are not evenly distributed among countries. World trade evens out this disparity, but in times of unrest, trade can be cut off. At one time the U.S. was once a leader in production of rare earth elements, those elements so important in electronics. Now 97% of the production of these elements comes from China (**Figure 769**). In 2010, in a dispute over Japan's detention of a Chineses fishing trawler caption who was fishing in waters controlled by Japan but long claimed by China, the Chinese government stopped the sale of rare earth elements to Japan. An article in *The New York Times* (Bradsher, 2010) stated that, "Japan has been the main buyer of Chinese rare earths for many years, using them for a wide range of industrial purposes. Some of these include glass for solar panels, small steering control motors in conventional gasoline-powered cars, for motors in hybrid cars like the Toyota Prius, and for magnets. The U.S. response to this incident was to consider a bill to subsidize the revival of the American rare earth industry at their mine in Mountain Pass, California, which closed in 2002. American defense depended on rare earth elements for rangefinders on tanks, sonar systems on Navy vessels, control vanes on Air Force smart bombs, and motors for guided missiles."

Bradsher (2010) noted that the U.S. was the main supplier of oil to Japan in the 1930s, and that a U.S. oil embargo against Japan in 1941 is the reason many historians cite for the attack on Pearl Harbor. Arab states used oil exports as a political weapon in 1956, 1967, and 1973. In similar fashion, China was using their monopoly on rare earth elements as political leverage against other governments. Today European dependence on Russian natural gas and oil makes western governments susceptible to embargoes over political disagreements. The map of major European gas pipelines in **Figure 770** shows Russia to be the main supplier of natural gas. Countries crossed by major pipelines, such as Belorussia and Ukraine, are battle grounds of both European and Russian interests.

Oil in Mississippi. The Works Progress Administration (WPA) was a federal administration created in 1935 during the Great Depression to employ millions of mostly unskilled men to carry our public works projects. These projects included a broad sector of the workforce in a variety of jobs, from the construction of public buildings and roads to the employment of musicians, artists, writers, actors and directors in art, drama, media, and literacy projects. At its peak in 1938, it employed three million men, women, and youths. It was at this time that the Mississippi Geological Survey as sponsor pledged $12,768 to obtain a Federal fund of $106,193 for the purpose of surveying the geology of ten counties. Of the pledged state funds, the State Legislature appropriated less than $4,000, and the ten counties provided the balance of $9,000. The second county surveyed was Yazoo County, where geologist Fred Mellen found the Moodys Branch Formation outcropping on Perry Creek some 250 feet above its normal position, indicating a dome favorable for oil and gas accumulation. After a press release on April 12, 1939, Union Producing Company drilled the #1 Woodruff well at the site, which was completed on August 29, 1939, and proved to be the first successful commercial oil well in Mississippi. Since that time, Tinsley Oil Field has produced some 200 million barrels of oil and is still producing under tertiary recovery with the injection of carbon dioxide gas.

Following the discovery of the Tinsley Oil Field in 1939, Germany invaded Poland and began a march on the Galacian and Romanian oilfields. War quickly spread to North Africa and to the Pacific, including oil-rich British Malaya and the Dutch East Indies (Japanese paratroopers seized the Dutch oil fields largely intact). To conserve oil and encourage exploration, the U.S. Government established the Office of Petroleum Coordination and staffed it with 72 leaders from America's oil industry. As the newest of the major oil producers, Mississippi's oil potential seemed unlimited. Drilling in the state reached record levels, and, in the years from 1943-1945, there were large oil finds at Brookhaven, Eucutta, Cranfield, Heidelberg, Mallalieu, and Baxterville. Major gas finds included Gwinville, Soso, and Hub. By the war's end, the state's proven reserve was placed at one billion barrels of oil and 3.5 trillion cubic feet of gas (after Alan Cockrell, 2005, Drilling Ahead; University Press of Mississippi, p. xxii).

Discoveries continued, and, in 1960, state government and the oil industry partnered to build a new facility in Jackson to house the Mississippi Geological Survey and the survey's core and sample repository. By August 1, 1965, the core repository was full of core and samples; space had run out. Fred Mellen, then the State Geologist, circulated a petition to Governor Paul B. Johnson that was signed by politicians (Ross Barnett), those in the oil industry (including MDEQ's Roy Furrh's father and Dan Morse's father and grandfather), and those in the Mississippi Gem and Mineral Society (signed by Dockery's parents and Heather Pitts' grandparents) to build a new and modern core and sample library. The petition succeeded only in fostering a cheaper solution—adding on to the existing facility.

Mississippi's core and sample facility grew as a string of metal buildings, which housed a wealth of new oil and gas well samples (**Figure 806**). The facility supported Mississippi's oil industry through the boom times. By January 1, 1970, the year of peak oil production for the nation, Mississippi ranked 7th among oil producing states. Following 1970

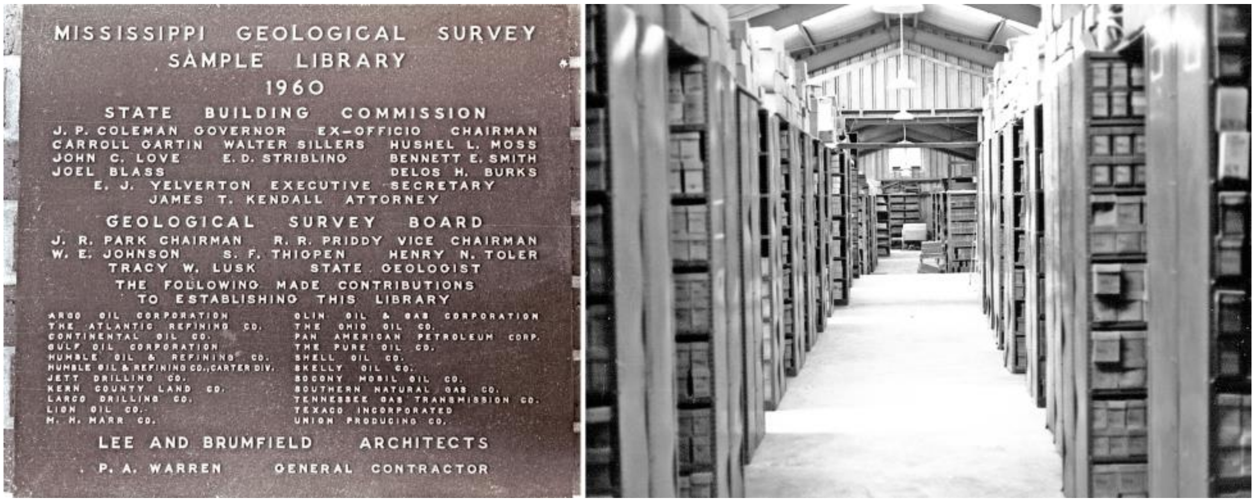


Figure 771. Left, dedication plaque at MDEQ's core and sample library, listing 12 oil industry companies that partnered with the state to build the facility in 1960. Right, a long line of multiple metal buidings house the core and sample collection. Pictures were taken around 1980. Image 2653.

there was a decline in domestic production and an increased dependence on foreign oil. Today, an upturn in domestic production has come about through advances in drilling technologies, which have unlocked new reservoir possibilities. These new technologies are being used in Mississippi's Black Warrior Basin and the southwestern part of the Mississippi Interior Salt Basin. Our state's next big oil find may be "hiding" in a core or sample box on a shelf in MDEQ's Core and Sample Library (**Figure 771**).

Mississippi Lignite. The use of Mississippi lignite for electric power generation utilizes a local energy resource and protects against market fluctuations in the price of oil and gas. The Red Hills Mine in Choctaw County, Mississippi (**Figure 772**), produces 3.2 million tons of lignite per year to fuel a 440 megawatt generating plant.

Figure 772. Lignite seams in the Red Hills Lignite Mine as pointed to by James Starnes. Picture was taken on September 29, 2014. Image 2654.

REFERENCES CITED

Albertson, P. E., and J. B. Dunbar, 1992, Paleobotanic portrayal of the Pearl River, Leake and Madison Counties, Mississippi, during the Quaternary Period: Journal of the Mississippi Academy of Sciences, v. 37, issue 1, p. 41.

Alley, W. M., and R. Alley, 2013, Too hot to touch. The problem of high-level nuclear waste: Cambridge University Press, 370 p.

Allison, M. L., 2001, Hutchinson, Kansas: a geologic detective story: Geotimes, v. 46, no. 10, October 2001, p. 14-18.

Altinakar, M. S., M. Z. McGrath, V. P. Ramalingam, and H. Omari, 2010, 2D modeling of Big Bay Dam Failure in Mississippi: Comparison with field data and 1D model results: Ole Miss Project 63891—River Flow 2010 Conference.

Amundson, R., and D. H. Yaalon, 1995, History of soil science. E. W. Hilgard and John Wesley Powell: Efforts for a joint Agricultural and Geological Survey: Soil Science Society of America Journal, v. 59, p. 4-13.

Arthur, J. K., 2001, Hydrogeology, model description, and flow analysis of the Mississippi River alluvial aquifer in northwestern Mississippi: U. S. Geological Survey, Water-Resources Investigations Report 01-4035, 47 p.

Arthur, J. Kerry, and Richard E. Taylor, 1998, Groundwater flow analysis of the Mississippi Embayment aquifer system, south-central United States: U. S. Geological Survey, Professional Paper 1416-I, 48 p., 9 pl.

Associated Press, 1979, Close Tatum ecologist says: Clarion Ledger, May 25, 1979, p. 3A-4A.

Associated Press, 1979, Radioactivity reading at Tatum due to contaminated lab utensil: Clarion-Ledger, June 7, 1979, p. 8B.

Associated Press, 1980, Legal snarl stalls Tatum Dome radiation test: Clarion-Ledger, July 16, 1980, p. 6B.

Associated Press, 2005, Miss. sues Memphis for water tapping: The Clarion-Ledger, Sunday, March 6, 2005, p. 4B.

Associated Press, 2008, Pharmaceuticals taint water supply. Scientists ponder long-term effects: The Clarion-Ledger, March 10, 2008, p. 2A.

Bailey, B., 2004, Aquifer sustainability is everybody's business: Mississippi Farm Country, v. 80, no. 2, p. 16, 30.

Baker, M., and W. Graham, 2008, Dam failure investigation approaches: Association of State Dam Safety Officials, Annual Conference, Indian Wells, California, September 2008; Recamation, Managing Water in the West, U.S. Department of the Interior, Bureau of Reclamation, Technical Paper, July 23, 2008, p. 10.

Barone, J. A., 2005, The historical distribution of prairies in the Jackson Prairie Belt and in western Mississippi: Journal of the Mississippi Academy of Sciences, v. 50, no. 2, p. 144-148.

Baughman, W. T., 1971, Rankin County Geology, p. 11-108, pl. 1-4, *in* Baughman, W. T., T. E. McCutcheon, A. R. Bicker, Jr., T. H. Dinkins, Jr., and T. N. Shows, Rankin County Geology and Mineral Resources: Mississippi Geological Survey, Bulletin 115, 226 p.

Baughman, W. T., and J. E. McCarty, 1974, Water resources of Wayne County, p. 241-293, *in* May, J. H., W. T. Baughman, J. E. McCarty, R. C. Glenn, W. B. Hall, 1974, Wayne County Geology and Mineral Resources: Mississippi Geological Survey, Bulletin 117, 293 p., 4 pl.

Baydala, K., 2007, Water 'safe,' but problems linger: Clarion-Ledger, Wednesday, June 6, 2007, p. B1, B3.

Berest, P., and H. Djizanne, 2012, Rapid depressurizations: can they lead to irreversible damage?: Solultion Mining Research Institute Spring 2012 Technical Conference, Regina, Saskatchewan, Canada, 23-24 April 2012, p. 1-12.

Bérestm P., and B. Brouard, 2002, Safety of salt caverns used for underground storage: Proceedings of the 8th Portuguese Congress for Geotechnique, April 15-18, 2002, Lisbon, Portugal.

Bicker, A. R., Jr., 1972, Salt water disposal wells in Mississippi: Mississippi Geological Survey, Information Series MGS-72-4, 92 p.

Blake, E., 2006, Mississippi highlands: Mississippi Farm Country, v. 82, no. 4, July/August, 2006, p. 24 -25, 38.

Bograd, M. B. E., 1993, Mississippi origins of the careers of E. W. Hilgard and E. A. Smith: Mississippi Geology, v. 14, no. 2, p. 21-23.

Bograd, M. B. E., 2008, Mining in streams: Policy questions for Mississippi (abstract): Journal of the Mississippi Academy of Sciences, v. 53, no. 1, p. 62.

Boswell, E. H., 1963, Cretaceous aquifers of northeastern Mississippi: Mississippi Board of Water Commissioners Bulletin 63-10, 202 p.

Boswell, E. H., and G. A. Bednar, 1985, Ground-water resources of the Natchez area, Mississippi: U. S. Geological Survey, Water-Resources Investigations Report 84-4341, 53 p.

Bowman, J., 2014, Lake Tanipahoa has new life: msnewsnow.com, WLBT, posted July 9, 2014.

Brieger, J. F., 1980, Hometown Mississippi: privately published, 2nd edition, 557 p.

Brown, C. A., 1938, the flora of Pleistocene deposits in the western Florida parishes, West Feliciana Parish, and East Baton Rouge Parish, Louisiana: Louisiana Geological Survey Bulletin 12, p. 59-96, pl. 9-15.

Brown, G. F., 1947, Geology and artesian water of the Alluvial Plain in northwestern Mississippi: Mississippi Geological Survey, Bulletin 65, 424 p., 13 pl.

Brown, G. F., V. M. Foster, R. W. Adams, E. W. Reed, and H. D. Padgett, Jr., 1944, Geology and groundwater resources of the coastal area in Mississippi: Mississippi Geological Survey, Bulletin 60, 166 p., 14 pl., 18 tables.

Bryant, C., 1995, The Tertiary-Quaternary aquifer relation in northwestern Mississippi: Mississippi Water Resources Conference, 1995 Proceedings, p. 66-75.

Bryant, C. and S. Dowdy, 1998, Mississippi River/ alluvial aquifer interaction at specific sites in northwestern Mississippi: Mississippi Water Resources Conference, 1998 Proceedings, p. 194-205.

Bryant-Byrd, C., 2002, An atlas of water level data from wells screened in the Mississippi River Valley alluvial aquifer in northwestern Mississippi: Mississippi Office of Land and Water Resources, Hydrologic Investigations Report 2002-1, v. 1, 8 p., plus appendixes, v. 2, 26 maps, 1 pl.

Caplenor, C. D., R. E. Bell, J. Brook, D. Caldwell, C. Hughes, A. Regan, A. Scott, S. Ware, and M. Wells, 1968, Forests of west central Mississippi as affected by loess, p. 205-267, *in* Snowden, J. O., Jr., R. R. Priddy, and C. D. Caplenor, et al., Loess investigations in Mississippi: Mississippi Geological Survey, Bulletin 111, 267 p.

Carey, A. E., C. B. Dowling, and R. J. Poreda, 2004, Alabama Gulf Coast groundwaters: ^{4}He and ^{14}C as groundwater-dating tools: Geology, v. 32, no. 4, p. 289-292.

Chapman, S. S., B. A. Kleiss, J. M. Omernik, T. L. Foti, and E. O. Murray, 2004b, Ecoregions of the Mississippi Alluvial Plain: U. S. Environmental Protection Agency, 1 sheet, map scale 1:1,150,000.

Childress, S. C., M. Bograd, and J. C. Marble, 1976, Geology and man in Adams County, Mississippi: Mississippi Geological Survey, Environmental Series No. 4, 188 pl., 8 plate in pocket.

Clarion-Ledger, 1980, Carter blows it on nuclear waste storage issue: Clarion-Ledger, February 17, 1980, p. 3I.

Clarion-Ledger/Jackson Daily News, 1980, Mudslide kills 3 in Natchez: Clarion-Ledger/Jackson Daily News, March 30, 1980, p. 1A, 14A.

Clarion-Ledger, 2005, Notice to customer: The Clarion-Ledger, Thursday May 12, 2005, p. 7B.

Charlier, T., 1998, Memphis taps into DeSoto County's well levels: The Commercial Appeal, November 16, 1998, p. A1, A9.

Conant, L. C., Geology, in Conant, L. C., and T. E. McCutcheon, 1942, Union County Mineral Resources: Mississippi Geological Survey, Buletin 45, 158 p., geologic map one sheet.

Cornelius, E., 1819, On the geology, mineralogy, scenery, and curiosities of parts of Virginia, Tennessee, and the Alabama and Mississippi territories, &c. with miscellaneous remarks, in a letter to the editor: American Journal of Science, v. 1, p. 214-226, 317-331.

Crider, A. F., 1906, Geology and mineral resources of Mississippi: U. S. Geological Survey, Bulletin 283, 99 p., 4 pl. including a foldout state geologic map. Wailes, B. L. C., 1854, Report on the Agriculture and Geology of Mississippi: E. Barksdale, State Printer, 371 p., 12 pl.

Davis, M. B., 1983, Holocene vegetational history of the eastern United States, p. 166-181, in Wright, H. E., Jr., (ed.), Late Quaternary Environments of the United States. Volume 2. The Holocene. University of Minnesota Press, Minneapolis, 277 p.

Davis, W. M., 1899, The drainage of cuestas: Geologists' Association, London, Proceedings, v. 16, pt. 2 (May), p. 75-93.

DeRoy, G., 2007, City flushing pipes to clear out foul water: Clarion-Ledger, Wednesday, May 30, 2007, p. A1, A4.

Dockery, D. T., III, 1976, Depositional systems in the upper Claiborne and lower Jackson groups (Eocene) of Mississippi: Master's Thesis, Department of Geology, University of Mississippi, 109 p.

Dockery, D. T., III, 1986, Puncuated succession of Paleogene mollusks in the northern Gulf Coastal Plain: Palaios, v. 1, no. 6, p. 582-589.

Dockery, D. T., III, 2002b, The geology of ground water in Mississippi: A commentary: The 32nd Annual Mississippi Water Resources Conference, April 23-24, 2002, Proceedings (published on CD).

Dockery, D. T., III, 2004a, Faith and fossils: Mississippi Geological Society Bulletin, v. 52, no. 5, p. 10-11.

Dockery, D. T., III, 2005, Engineering geologic failures and cost overruns: Examples from Mississippi (abstract): 54th Annual Meeting, Southeastern Section, Geological Society of America, March 17-18, Biloxi, Mississippi, Abstracts with Programs, v. 37, no. 2, p. 49.

Dockery, D. T., III, and P. Mason, 2002, The topography of Mississippi: Mississippi Geological Society Bulletin, v. 50, no. 8, p. 10-13.

Dockery, D. T., III, J. E. Starnes, D. E. Thompson, and L. Beiser, 2008, Rocks and fossils found in Mississippi's gravel deposits: Mississippi Office of Geology, Circular 7, 24 p., 12 color plates.

Dockery, D. T., III, and D. E. Thompson, 2016, The Geology of Mississippi: Mississippi Department of Environmental Quality and University Press of Mississippi, 751 p.

Doherty, T., 2014, Potential solutions for Lake Serene dams on the horizon: HattiesburgAmerican.com, February 21, 2014.

Domonoske, C., 2016, U.N. admits role in Haiti cholera outbreak that has killed thousands: NPR, posted August 18, 2016.

Dougherty, K., 2010, Weapons of Mississippi: University Press of Mississippi, 265 p.

Doughty, S, C., D. J. Gill, and D. C. Blouin, 1994, A systematic survey of freeze-damaged palms in the New Orleans area after the 1989 freeze of the century: Principles, v. 38, no. 2, p. 64-72.

Dolbi, R., 2005a, DeSoto County sues Memphis over water: DeSoto Times, Thursday May 5, 2005, issue, p. A1, A8.

Dolbi, R., 2005b, University to study aquifer. Underground storage area to include DeSoto County: DeSoto Times, Thursday August 18, 2005, issue, p. A1.

Douglas, H., 2000, Soil and southern history: Agricultural History, v. 74, issue 4, fall 2000, p. 723-758.

Duke Energy Gas Transmission, 2001, Duke Energy plans to develop Mississippi salt dome [in Copiah County] for natural gas storage: News Release, June 25, 2001.

Dunbar, J. B., and E. J. Coulters, 1988, Geomorphic investigation of the Shoccoe Dam Project area: Project Report, U.S. Army Engineers Waterway Experiment Station, Vicksburg, Mississippi, 84 p., 8 pl., 7 appendices.

Dunston, C. E., 1910, Forest conditions of Mississippi: Mississippi Geological Survey, Bulletin 7, 76 p.

Eason, B., 2012, H2Oh, gross: The Clarion Ledger, Sunday October 7, 2012, front page and page 2A.

Elliott, J. D., 1998, Chapter II. Historical Overview, p 1 -44, *in* O'Hear, J. W., J. R. Atkinson, J. D. Elliott, E. A. Boudreaux, and J. R. Underwood, 1998, An archaeological and historical investigation of the Natchez Trace Choctaw Agency, Madison County, Mississippi: Draft Report Submitted by the Cobb Institute of Archaeology, Mississippi State University.

Ericksen, R. L., 1995, Electrical resistivity values (RW's) and chemical data determined from analyses of produced formation waters from oil and gas well test in Mississippi: Mississippi Office of Geology, Report of Investigations 3, 42 p., 4 pl.

Ericksen, R. L., 1999, NORM study completes first project year in Mississippi: Mississippi Geology, v. 20, no. 1, March 1999, p. 1-10.

Ericksen, R. L., 1999, Evaluations of radionuclides of uranium, thorium, and radium associated with production fluids, precipitates, and sludges from oil, gas, and oilfield brine injection wells in Mississippi: Semi-Annual Technical Progress Report, September 1, 1998 to February 28, 1999, DOE Award Number DE-FG26-97BC15305, Mississippi Office of Geology, 15 p., 4 fig.

Ewing, R. C., 2011, Foundation repairs due to expansive soils: Eudora Welty House, Jackson, Mississippi: Journal of Performance of Constructed Facilities, January/February 2011, v. 25, no. 1, p. 50-55.

Field, R. W., D. J. Steck, B. J. Smith, C. P. Brus, E. L. Fisher, J. S. Neuberger, C. E. Platz, R. A. Robinson, R. F. Woolson, and C. F. Lynch, 2000, Residential radon gas exposure and Lung Cancer. The Iowa Radon Lung Cancer Study: American Journal of Epidemiology, v. 151, no. 11, p. 1091-1102.

Feldman, D. L., and J. O. Elmendorf, 2000, Final Report. Water supply challenges facing Tennessee: Case study analyses and the need for long-term planning: Prepared for the Environmental Policy Office, Tennessee Department of Environment and Conservation, Nashville, Tennessee, 106 p.

Foster, V. M., 1940, Geology, p. 1-172, *in* V. M. Foster and T. E. McCutcheon, Lauderdale County Mineral Resources: Mississippi Geological Survey, Bulletin 41, 246 p.

Frankel, T. C., 2014, The toxin that shut off Toledo's water? The feds don't make you test for it: The Washington Post, posted August 11, 2014.

Gandl, L. A., 1982, Characterization of aquifers designated as potential drinking water sources in Mississippi: U. S. Geological Survey, Water Resources Investigations, Open-File Report 81-550, 90 p., 3 pl.

Gandl, L. A., and C. A. Spiers, 1980, Results of water quality sampling near Richton, Cypress Creek, and Lampton salt domes, Mississippi: U.S. Geological Survey, Open-File Report OF 80-443.

Gates, J. E., 2004, U.S. roadwork cited in erosion: The Clarion-Ledger, November 12, 2004, p. 1B.

Gill, D., 2014, Repeated freezes are tough on tropical plants, but New Orleans gardens have been through worse: The Times-Picayune, posted January 29, 2014.

Gillhaus, A., 2007, Natural gas storage in salt caverns—Present status, developments and future trends in Europe: Solution Mining Research Institute, Spring 2007 Conference, April 29—May 2, 2007, Basel, Switzerland.

Gonthier, G. and P. Aharon, 1990, Groundwater sources and flow patterns derived from stable isotopes and elemental chemistry of the southeast Louisiana freshwater aquifers: Gulf Coast Association of Geological Societies Transactions, v. 40, p. 251-263.

Groen, J., H. Kooi, V. Post, and J. J. de Vries, 2000, Fresh and moderately brackish groundwater in coastal plains and continental shelves: Past and ongoing natural processes, Proceedings, SWIM, 16, Miedzyzdroje-Wolin Island, Amsterdam, Netherlands, Nicholas Copernicus University, v. 80, p. 73-80.

Gustke, C., 2016, Pollution crisis is choking the Chinese economy: CNBC, posted February 11, 2016.

Harrelson, D. W., W. D. Easom, and W. H. Johnson, 1980, The Bureau of Geology's electric logging program: Mississippi Geology, v. 1, no. 1, p. 8-10.

Harris, G. D., 1896, The Midway Stage: Bulletins of American Paleontology, v. 1, no. 4, 156 p., 15 pl.

Harrist, R., 1979, Radiation Evacuation in Miss.: Times Picayne, May 26, 1979, p. 1, 11.

Hartfield, P., 1994, Headcuts and their effect on freshwater mussels, p. 131-141, in Cummings, K. S., A. C. Buchanan, and L. M. Kochs, eds, Conservation and Management of Freshwater Mussels: Proceedings of a UMRCC sysposium, October 12-14, 1992, St. Louis, Missouri, Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Harvey, C., 2016, The staggering economic cost of air pollution: The Washington Post, posted January 29, 2016.

Heitmuller, F., J. Ables, and G. Rader, 2017, Geomorphic adjustments along Bayou Pierre, Mississippi (2004-2016) (abstract): Mississippi Academy of Sciences, Journal, v. 62, no. 1, p. 82-83.

Hilgard, E. W., 1860, Report on the geology and agriculture of the state of Mississippi: E. Barksdale, State Printer, Jackson, Mississippi, 391 p., map.

Hilgard, E. W., 1884, Physio-geographic and agricultural features of the State of Mississippi: U. S. 10th Census of 1880, v. 5, p. 209-345, map.

Hilgard, E. W., 1907, Soil. Their formation, properties, composition, and relations to climate and plant growth in the humid and arid regions: The MacMillan Company, New York, 593.

Hill, F., J. H. Hoffmann, and K. H. Erustun, 1986, Potential development of fresh water resources from the lower Wilcox aquifer in the Heidelberg Oil Field, Heidelberg, Mississippi: Proceedings Mississippi Water Resources Conference 1986, p. 53-57.

Hille, F., J. H. Hoffmann, and K. H. Erustun, 1986, Potential development of fresh water resources from the Lower Wilcox aquifer in the Heidelberg Oil Field, Heidelberg, Mississippi, p. 53-57, *in* Mississippi Water Resources Conference Proceedings, 1986, 98 p.

Hinton, M., 2006, Pearl Street residents told to be ready to evacuate: The Vicksburg Post, v. 124, no. 79, Monday, March 20, 2006, p. A1, A9.

Hoffmann, J. H., and P. E. Grantham, 2000a, Potentiometric map of the Meridian-upper Wilcox aquifer in Mississippi, spring 1993 to spring 1995: Mississippi Office of Land and Water Resources, OLWR Hydrologic Map 00-1, 20 p., 1 map.

Hoffmann, J. H., and P. E. Grantham, 2000b, Potentiometric map of the lower Wilcox aquifer in Mississippi, spring 1993 to spring 1995: Mississippi Office of Land and Water Resources, OLWR Hydrologic Map 00-3, 18 p., 1 map.

Howe, H. V., 1964, Hilgard as a geologist, p. 33-64, *in* Bicker, A. R., D. W. Engelhardt, H. V. Howe, M. K. Kern, F. F. Mellen, W. H. Moore, and W. S. Parks, Mississippi Geologic Research Papers-1964: Mississippi Geological Survey, Bulletin, 104, 127 p.

Ivany, L. C., W. P. Paterson, and K. C. Lohmann, 2000, Cooler winters as a possible cause of mass extinctions at the Eocene/Oligocene boundary: Nature, v. 407, no. 6806, p. 887-890.

Jennings, S. P., 1994, Hydrogeology and aquifer potential of the Paleozoic rocks of northeastern Mississippi: Mississippi Office of Land and Water Resources, Hydrologic Investigations Report 94-1, 54 p., 2 maps.

Jennings, S. P., 2001, Preliminary report on the hydrogeology of the Tertiary aquifers in the Alluvial Plain region of northwestern Mississippi -- Subcrop geologic map and cross sections: Mississippi Office of Land and Water Resources, Open-File Report 01 -101, 3 sheets.

Jenny, H., 1961, E. W. Hilgard and the birth of modern soil science: Collana Della Rivista "Agrochimica," Pisa, 144 p.

Johnson, W. H., 1982, The Waynesboro Sand: Mississippi Geology, v. 2, no. 4, p. 1-8.

Kane, H. T., 1947, Natchez on the Mississippi: Morrow & Company, 373 p.

Kalkhoff, S. J., 1982, Secific conductance and dissolved chloride concentrations of freshwater aquifers and streams in petroleum producing areas in Mississippi: U. S. Geological Survey, Open-File Report 82-353, 33 p.

Kalkhoff, S. J., 1986, Brine contamination of freshwater aquifers and streams in petroleum producing areas in Mississippi: U. S. Geological Survey, Water-Resources Investigations Report 85-4117, 106 p.

Kalkhoff, S. J., 1986, Brine contamination of shallow ground water and streams in the Brookhaven Oil Field, Lincoln County, Mississippi: U. S. Geological Survey, Water-Resources Investigations Report 86-4087, 57 p.

Kansas State University, 2008, Freshwater pollutions costs US at least $4.3 billion a year: ScienceDaily, posted November 12, 2008.

Kim, J.-H., J. van der Meer, S. Schouten, P. Helmke, V. Willmott, F. Sangiorgi, N. Koc, E. C. Hopmans, J. S. S. Damste, 2010, New indices and calibrations derived from the distribution of crenarchaeal isoprenoid tetraether lipids: Implications for past sea surface temperature reconstructions: Geochimica et Cosmochimica Acts, v. 74, p. 4639-4654.

Kobashi, T., and E. L. Grossman, 2003, The oxygen isotopic record of seasonality in *Conus* shells and its apllication to understanding late Middle Eocene (38 Ma) climate: Paleontological Society of Japan, Paleontological Research, v. 7, no. 4, p. 343-355.

Kobashi, T., E. L. Grossman, T. E. Yancey, and D. T. Dockery III, 2001, Reevaluation of conflicting Eocene tropical temperature estimates: molluskan oxygen isotopic evidence from warm low latitudes: Geology, v. 29, no. 11, p. 983-986.

Kubissa, D. W., 1979, Scientists to perform more tests at Tatum Dome: Clarion-Ledger, April 6, 1979, p. 3A.

Lang, D. J., J. Duckworth, B. Shankle, N. R. Buell-McGrew, B. Robinson, and R. Lemus, 2011, Establishment of switchgrass on reclaimed coal mine soil: PowerPoint Presentation presented on October 18, 2011, at the ASA, CSSA, and SSSA International Annual Meetings, October 16-19, San Antonio, Texas, on October 18, 2011.

Lang, D. J., G. Hawkey, B. Chow, and V. Maddox, 2006, Revegetation success at the Red Hills Lignite Mine in Mississippi: Paper presented at the 2006 Billings Land Reclamation Symposium, June 4-8, 2006, Billings, Montana, and jointly published by BLRS and ASMR, R. I. Barnhisel (editor), 3134 Montavesta Road, Lexington, KY 40502.

Lang, J. W., and E. H. Boswell, 1960, Public and industrial water supplies in a part of northern Mississippi: Mississippi Geological Survey, Bulletin 90, 104 p., 1 pl.

Lee, M.-K., J. A. Saunders, and A. Uddin, 2003, Geochemical and hydrologic considerations of evolution of groundwaters in a portion of the Mississippi Embayment: Southeastern Geology, v. 42, no. 2, p. 83-98.

Lobeck, A. K., 1979, Physiographic diagram of the United States: The Geographic Press (formerly of Columbia University), a Division of Hammond, New Jersey, 8 p.

Logan, W. N, 1916, Marls and limestone of Mississippi: Mississippi Geological Survey, Bulletin 13, 82 p.

Lord, A. S., C. A. Rautman, and K. M. Looff, 2007, Geologic Technical Assessment of the Richton Salt Dome, Mississippi, for potential expansion of the U.S. Strategic Petroleum Reserve: Sandia National Laboratories, 40 p.

Lovley, D. R., F. H. Chapelle, and E. J. P. Phillips, 1990, Fe(III)-reducing bacteria in deeply buried sediments of the Atlantic Coastal Plain: Geology, v. 18, no. 10, p. 954-957.

Lowe, E. N., 1911a, A preliminary study of the soils of Mississippi: Mississippi Geological Survey, Bulletin 8, 220 p.

Lowe, E. N., 1915, Mississippi, its geology, geography, soils and mineral resources: Mississippi Geological Survey, Bulletin 12, 355 p., 1 map: "Geological Map of Mississippi."

Lowe, E. N., 1919, Mississippi, its geology, geography, soil and mineral resources: Mississippi Geological Survey, Bulletin 14, 346 p.

Lowe, E. N., 1925, Geology and mineral resources of Mississippi: Mississippi Geological Survey, Bulletin 20, 151 p.

Lucas, S., 2004, Tougaloo, Natchez preservation projects lauded: The Clarion-Ledger, Wednesday, October 6, 2004, p. 1E.

Lucas, S., 2013, Manship house repairs unearth little treasures: The Clarion-Ledger, Friday, January 25, 2013, p. 1B, 3B.

Lusk, T. W., 1951, Ground water investigations along Bogue Phalia between Symonds and Malvina, Bolivar County: Mississippi Geological Survey, Bulletin 72, 19 p., 4 pl.

Lusk, T. W., 1963a, Problem of desiccation sinking at Clarksdale, p. 60-75, *in* Kern, M. K., W. H. Moore, T. W. Lusk, L. Hubricht, E. H. Rainwater, Mississippi geologic research papers-1962: Mississippi Geological Survey, Bulletin 97, 106 p.

Manning, E. M., and D. T. Dockery III, 1992, A guide to the Frankstown vertebrate fossil locality (upper Cretaceous), Prentiss County, Mississippi: Mississippi Office of Geology, Circular 4, 43 p., 12 plates.

Martin, R., 1966, Paleogeomorphology and its application to exploration for oil and gas (with examples from western Canada): American Association of Petroleum Geologists, Bulletin, v. 50, no. 10, p. 2277-2311.

Maxwell, B., 2011a, Field measurements of Yazoo Clay reveal expansive soil design issues: Journal of Performance of Constructed Facilities, January/February 2011, v. 25, no. 1, p. 18-23.

Maxwell, B., 2011b, Investigation and repair of a four-story building damaged by Yazoo Clay: Journal of Performance of Constructed Facilities, January/February 2011, v. 25, no. 1, p. 45-49.

McCann, N., 2002, Despite rain, city's bluff work 'designed to last': The Natchez Democrat, published Wednesday, October 30, 2002, 12:42 AM CST.

McCann, N., 2003, Rain leaves earthslides in Natchez: The Natchez Democrat, published March 7, 2003, 12:44:26 AM CDT.

McIlwain, J. A., D. W. Schmitz, and J. H. May, 2007, Hydrogeologic assessment of a proposed reservoir site, Smith County, Mississippi (abstract): Journal of the Mississippi Academy of Sciences, v. 52, no. 1, p. 85.

Mellen, F. F., 1958, Cretaceous Shelf Sediments of Mississippi: Mississippi Geological Survey, Bulletin 85, 112 p.

Minshew, V. H., C. A. Gazzier, L. P. Malbrough, and T. H. Waller, 1974, Environmental Geological Analysis: Jackson County, Mississippi, Mississippi Mineral Resources Institute, The University of Mississippi, in fulfillment of Mississippi Office of Science and Technology, Office of the Governor, Dr. P. T. Bankston, Director, Agreement Number 73-3 (UN 044250003), 228 p., plus physical properties map, active processes map, biological assemblages map, and environmental geologic map.

Mississippi Water Resources Management Planning Council, 1995, A water management plan for the State of Mississippi, June 30, 1995, 40 p.

Mitchell, J., 2004, Ex-rail chief: Defective rail likely: Clarion-Ledger, Thursday, April 8, 2004, p. 7A.

Moran, L. P., 1997, Soils of native prairie remnants in the Jackson Prairie region of Mississippi: Mississippi Agriculture and Forestry Experiment Station, Bulletin 1067, 13 p.

Morse, W. C., 1935c, The geologic history of the Vicksburg National Military Park area: Mississippi Geological Survey, Bulletin 28, 20 p., plus map.

Mossa, J., 2006, Quantifying channel planform change: Papers of the Applied Geography Conferences (2006), v. 29, p. 65-70.

Mossa, J., and D. Coley, 2006, Channel stability and instability in the Pascagoula River and tributaries, Mississippi: Proceedings of the 36th Annual Mississippi Water Resources Conference, Jackson, Mississippi, p. 70-78.

Muttoni, G., and D. V. Knet, 2007, Widespread formation of cherts during the early Eocene climate optimum: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 253, p. 348-362.

Myers, M. M., and S. P. Jennings, 2003, Hydrogeological investigation of the Haynes Lake area, Tishomingo State Park, Tishomingo County, Mississippi: Mississippi Office of Land and Water Resources (unnumbered report), December 2003, 3 p., plus map and 26 color illustrations on 13 pages.

Myers, W. M., D. W. Harrelson, and R. J. Larson, 2005, The impact of Vicksburg loess on the 1863 siege of Vicksburg, Mississippi (abstract): Geological Society of America, 2005 Abstracts with Programs, Southeastern Section, v. 37, no. 2, p. 46.

Newcomb, R., Jr., 1965, Configuration on the base of the fresh-ground-water section in Mississippi: Mississippi Board of Water Commissioners, Water Resources Map 65-1, 1 sheet.

Newcomb, R., Jr., 1975, Formation factors and their use in estimating water quality in Mississippi aquifers: U. S. Geological Survey, Water Resources Investigations Map 2-75.

Oakley, W. T., and D. E. Burt, Jr., 1992, Records of public-supply wells in Mississippi, 1991: U. S. Geological Survey, Open-File Report 92-82, 110 p.

Oivankin, S. M., 1996, Forensic geology: Geologic investigation as a tool for enforcement of environmental regulations, v. 17, no. 3, p. 45-50.

Ourlian, R., 1984, Questions linger 20 years after state nuclear test: Clarion-Ledger, June 29, 1984, p. 1A.

Patrick, D. M., L. Mao, and S. T. Ross, 1991, Accelerated erosion of the Bayou Pierre Basin, southwest Mississippi: characterization and causes, p. 36-44, *in* Daniel, B. J., editor, 1991, Proceedings of the Mississippi Water Resources Conference

Person, M., B. Dugan, J. B., Swenson, L. Urbano, C. Stott, J. Taylor, and M. Willett, 2003, Pleistocene hydrogeology of the Atlantic continental shelf, New England: Geological Society of America, Bulletin, v. 115, no. 11, p. 1324-1343.

Perkins, s., Johnstown Flood matched volume of Mississippi River: Science News, v. 176, no. 11, November 2009.

Pettry, D. E., and R. E. Switzer, 1993, Expansive soils of Mississippi: Mississippi Agricultural and Forestry Experiment Station, Bulletin 986, 29 p.

Pettus, G., 1999, Ex-WLBT sportscaster Fidler dies at age 39: The Clarion-Ledger, Tuesday May 4, 1999, Sports Section, p. 1D.

Picayune Item, 2005, Natchez seeks help with money for bluff work: Picayune Item, published Saturday, January 29, 2005, 5:08 PM CST.

Pittari, J., 2012a, Work continuing at Superfund site: The Picayune Item, February 11, 2012.

Pittari, J., 2012b, Work at Superfund site progressing: Picayune Item, June 28, 2012.

Pittman, W. E., 1983, Eugene W. Hilgard and scientific education in Mississippi: Geological Society of America, Abstracts with Programs, v. 15, no. 2, Southeastern Section Meeting, January 1983, p. 61.

Priddy, R. R., 1955, Fresh water strata of Mississippi as revealed by electrical log studies: Mississippi Geological Survey, Bulletin 83, 71 p., 1 pl.

Priddy, R. R., 1960, Madison County Geology: Mississippi Geological Survey, Bulletin 88, 123 p., 6 pl.

Prothero, D. R., L. C. Ivany, and E. A. Nesbitt, 2003, From greenhouse to icehouse, the marine Eocene-Oligocene transition: Columbia University Press, 541 p.

Raines, B., 2012, Ancient forest lies 10 miles off the Alabama coast: Alabama Local New, al.com, posted September 2, 2012.

Raines, B. 2017, Gulf's 60,000-year-old underwater forest spills its secrets in new documentary: Alabama Local News, al.com, posted June 25, 2017.

Raisz, E., 1957, Landforms of the United States, Sixth revised edition, 1957, to accompany Atwood's "Physiographic Provinces of North America," one sheet.

Reimer, P. J., 2004, Spots from rings: Nature, v. 431, issue no. 7012, October 28, 2004, p. 1047-1048.

Riddell, J. L., 1947, Orrin Lindsay's plan of ærial navigation, with a narrative of his explorations in the higher regions of the atmosphere and his wonderful voyage round the moon: The Southron, v. 7, no. 33, Friday, August 13, 1947, p. 1-2.

Riess, K., 1977, John Leonard Riddell: Tulane Studies in Geology and Paleontology, v. 13, no. 1-2, 110 p.

Rogers, J. D., The 1928 St. Francis Dam failure and the 1995/2005 La Conchita landslides: The emergence of engineering geology and its continuing role in protecting society: *in*, Guptill, P. D., and T. Gonzalez, eds., 2007 Guidebook for Field Trips, AEG 50th Anniversary Annual Meeting, Los Angeles, p. 79-198.

Rogers, J. D., Impacts of the 1928 St. Francis Dam failure on geology, civil engineering, and America: Association of Environmental and Engineering Geologist, 2007 Annual Meeting, Los Angeles, California, September 28, 2007, PowerPoint presentation.

Ross, S. T., M. T. O'Connell, D. M. Patrick, C. A. Latorre, W. T. Slack, J. G. Knight, and S. D. Wilkins, 2001, Stream erosion and densities of *Etheostoma rubrum* (Percidae) and associated riffle-inhabiting fishes: biotic stability in a variable habitat: Copeia, v. 4, p. 916-927.

Rucker, J. B., and J. O. Snowden, 1988, Recent morphologic changes at Dog Key Pass, Mississippi: The formation and disappearance of the Isle of Caprice: Gulf Coast Association of Geological Societies Transactions, v. 38, p. 343-349.

Russell, R. J., 1935, Slump near Fort Adams, Mississippi (abstract): Proceedings of the Geological Society of America for 1934, p. 104.

Sample, I., Ancient river network discovered buried under Saharan sand: The Guardian, posted November 10, 2015.

Saucier, R. T., 1994b, Geomorphology and Quaternary geologic history of the lower Mississippi Valley: U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi; v. 1, 364 p., Appendix A, 23 p., Appendix B, 11 p.; v. 2, 28 pl.

Schabilion, S., 1996, A Scrapbook of Time, 32 p.

Schleifstein, M., 1979, Studies show new radioactive elements at Tatum Dome: Clarion-Ledger, November 29, 1979, p. 3A.

Schleifstein, M., 1979, Health officials clear up 'muddy' Tatum discovery: Clarion-Ledger, November 30, 1979, p. 3A.

Schlermeier, Q., 2004, A rising tide: Nature, v. 428, no. 6979, March 11, 2004, p. 114-115.

Schneider, R., E. H. Roseboom, Jr., J. B. Robertson, and P. R. Stevens, 1982, U.S. Geological Survey research in radioactive waste disposal—fiscal year 1979: U.S. Geological Survey Circular 847, 74 p.

Schmitz, D. W., C. L. Wax, and J. W. Pote, 1999, Influence of water availability of settlement patterns: Proceedings of the Twenty-ninth Mississippi Water Resources Conference, April 7-8, 1999, p. 153-155.

Sheahan, J., and D. Coley, 2002, Historic brownfields bill becomes law: major victory for mayors as lengthy lobbying process pays off: The United States Conference of Mayor, website: Brownfields.

Seal, M. C., 1986, Investigation of ground-water contamination in a shallow aquifer at Benton, Mississippi: Mississippi Geology, v. 6, no. 4, June 1986, p. 1-4.

Seal, M. C., and C. W. Stover, 1984, Correction of seepage problems at Haynes Lake, Tishomingo State Park: Journal of the Mississippi Academy of Sciences, v. 29, Supplement, 1984 Abstracts, p. 20.

Shows, T. N., 1970, Water Resources of Mississippi: Mississippi Geological Survey, Bulletin 113, 161 p.

Sikes, V., 2005, County takes corrective steps after DEQ citing; The Yazoo Herald, February 23, 2005.

Skinner, H. C., 1983, John Leonard Riddell (geoscientist -inventor-educator): From Rensselaer to New Orleans (1827-1865) (abstract): Southeastern Section Meeting, Geological Society of America, January 1983, Abstracts with Programs, v. 15, no. 2, p. 61.

Skonieczny, C., P. Paillou, A. Bory, G. Bayon, L. Biscara, X. Crosta, F. Eynaud, B. Malaize, M. Revel, N. Aleman, J.-P. Barusseau, R. Vernet, S. Loper, and F. Grousset, 2015, African humit periods triggered the reactivation of a large river system in Western Sahara: Nature Communications, article number: 8751 (2015).

Slack, L. J., C. G. O'Hara, and W. T. Oakley, 1996, Brine contamination of ground water in the vicinity of the Brookhaven Oil Field, Lincoln County, Mississippi: U.S. Geological Survey, Water-Resources Investigations Report 96-4023, 27 p., 5 figures in pocket.

Smith, E. A., 1917, Memorial of Eugene Woldemar Hilgard: Geological Society of America, Bulletin, v. 28, p. 40-67.

Smith, L. M., 1986, Geologic investigation of bluff failure at Natchez, Mississippi (abstract): Mississippi Geological Society Bulletin, v. 34, no. 3, November 1986, p. 6.

Solanki, S. K., I. G. Usoskin, B. Kromer, M. Schüssler, and J. Beer, 2004, Unusual activity of the Sun during recent decades compared to the pervious 11,000 years: Nature, v. 431, issue no. 7012, October 28, 2004, p. 1084-1087.

Sontag, D., 2012, In Haiti, global failures on a cholera epidemic: The New York Times, posted March 31, 2012.

Spear, S., 1989, Salt dome blast has left jarring doubt: Clarion Ledger, October 22, 1989, p. 1A, 17A.

Stephenson, L. W., W. N. Logan, G. A. Waring, and C. S. Howard, 1928, The ground-water resources of Mississippi: U. S. Geological Survey, Water-Supply Paper 576, 515 p.

Stephenson, L. W., and W. H. Monroe, 1940, Upper Cretaceous deposits: Mississippi Geological Survey, Bulletin 40, 296 p.

Stewart, L., and J. F. Everett, 2002, A monitoring well network for the Mississippi Gulf Coast Oligocene-Miocene-Pliocene aquifer system: Mississippi Office of Land and Water Resources, Open-File Report 02-101, 12 p., plus figures and data.

Stover, C. W., and J. L. Coffman, 1993, Seismicity of the United States, 1568-1989 (revised): U. S. Geological Survey Professional Paper 1527, 418 p.

Stover, C. W., D. W. Harrelson, and W. H. Johnson, 1981, Monitor well construction and hydrological testing, Tatum Salt Dome, Lamar County, Mississippi, March-April 1981: Mississippi Office of Geology, Open File Report OF-4, 22 pages plus 40-page appendix and 6 geophysical logs.

Strom, E. W., 1998, Hydrogeology and simulation of ground-water flow in the Cretaceous-Paleozoic aquifer system in northeastern Mississippi: U. S. Geological Survey, Water-Resources Investigations Report 98-4171, 81 p.

Thompson, D. E., 2005, Solid-phase geochemical survey of the State of Mississippi; an atlas highlighting the distribution of As, Cu, Hg, Pb, Se, and Zn in stream sediments and soils: Mississippi Department of Environmental Quality, Office of Geology, online publication.

Thompson, D. E., A. E. Grosz, J. M. McNeal, and J. N. Grossman, 1998, Surface geochemistry of Mississippi to be surveyed: Mississippi Geology, v. 19, no. 2, p. 13-19.

U.S. EPA, Slurry Phase Bioremediation Application at the Southeastern Wood Preserving Superfund Site Canton, Mississippi, pages i, 1-27, in Office of Solid Waste and Emergency Response Technology Innovation Office, U.S. Environmental Protection Agency, Cost and Performance Reports.

Van Zandt, F. K., 1976, Boundaries of the United States and the several States: U. S. Geological Survey, Professional Paper 909, 191 p.

Vestal, F. E., 1942, Geology, p. 9-142, *in* Vestal, F. E. and T. E. McCutcheon, Adams County mineral resources: Mississippi Geological Survey, Bulletin 47, 200 p., plus geologic map.

Vestal, F. E., 1956, Panola County geology: Mississippi Geological Survey, Bulletin 81, 157 p.

Wailes, B. L. C., 1854, Report on the Agriculture and Geology of Mississippi: E. Barksdale, State Printer, 371 p., 12 pl.

Weaver, F. M., and S. W. Wise Jr., 1974, Opaline sediments of the southeastern coastal plain and Horizon A: biogenic origin: Science, v. 184, no. 4139, p. 899 -901.

Wieland, R., 1991, Jackson Prairie: Myth or reality?: Mississippi Museum of Natural Science (newsletter), v. 8, no. 1, January 1991.

Williams, Richard S., and Jane G. Ferrigno, 1999, Estimated present-day area and volume of glaciers and maximum sea level rise potential: http://pubs.usgs.gov/factsheet/fs133-99/gl_vol.html.